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SURVEY AND EXTENSION OF AFIT COMPUTER RESOURCES TO SUPPORT GRAD--ETC(U)
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SURVEY AND EXTENSION OF
COMPUTER RESOURCES TO SUPPORT
GRADUATE OPERATIONS RESEARCH EDUCATION

THESIS

AFIT/GOR/SM/78D-13 Robert M. Schumacher
Captain USAF

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6 SURVEY AND EXTENSION OF AFIT
COMPUTER RESOURCES TO SUPPORT
GRADUATE OPERATIONS RESEARCH EDUCATION.

THESIS

9 Master's thesis,

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

12 156p.

by

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Captain USAF

Graduate Operations Research

11 Dec 9 ~~ember 1978~~

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Preface

This research was performed to survey and extend the computer resources supporting graduate operations research education at the Air Force Institute of Technology (AFIT). If the research or the suggestions make using the computer a little easier or more productive for future graduate operations research students, then I will be satisfied.

I wish to thank Dr. Edward J. Dunne, Jr. for his suggestions and assistance. Also my thanks go to Bill and Molly Bustard for their helpfulness throughout the AFIT program. And finally, my total appreciation and gratitude for my wife, Joy, who provided constant encouragement and support especially during the thesis preparation.

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ABSTRACT

The historical relationship between operations research and the computer was developed using a search of the literature. The historical data was compiled into a timeline and bibliography. The analysis of the historical data concluded that operations research and the computer are in a synergistic relationship where developments in either field enhance the other field.

From the historical background and from the literature, a model of computer support for graduate operations research education was developed. The checklist based upon this model was used to evaluate portions of the Air Force Institute of Technology's Graduate Operations Research program.

After the results of a literature search on problem formulation was presented, a proposal for an automated method for algorithm selection was developed.

SURVEY AND EXTENSION OF AFIT

COMPUTER RESOURCES TO SUPPORT

GRADUATE OPERATIONS RESEARCH EDUCATION

I. INTRODUCTION

> "..., the computer has assisted the development and/or implementation of most of the OR methods in use today. It is clear to most that OR is vitally dependent upon the computer, for without it OR would be reduced to a theoretical science rather than the ever expanding field that it is."
> Dr. Billy E. Gillett (Ref 19:12)

The computer's role in higher education has become more important every year. In 1967 the United States President's Advisory Committee emphasized the critical need for our education system to use the computer in all aspects of education (Ref 49). The National Science Foundation in 1970 held the conference, "Computers in Instruction: Their Future for Higher Education." Again the growing role of the computer and its potential for improving the quality of education was emphasized (Ref 32). Here at the Air Force Institute of Technology (AFIT) in the Graduate Operations Research (GOR) program there is an emphasis on practical applications using the computer (Ref 3:40).

Almost all authorities agree there is a relationship between computer sciences and Operations Research. Dr. Billy E. Gillett, for example, believes that the computer has a vital role which is increasing all the time, but it is very difficult to define and properly explain. However for the Operations Research analyst it is important that the computer's role in analysis be understood. The question which spawned

this thesis is this, "What is the computer's relationship to the operations research analyst?".

Background

From reading and discussions it has become apparent that the computer is involved in the operations research analysis from problem formulation to selling the results. From the AFIT GOR students, information was received which described several of the computer interactions upon them. Several members of the AFIT faculty were interviewed using the questionnaire in Appendix A. The following is a list of some of those early observations.

1. The computer is tough to use.
2. The right program is hard to find.
3. The program documentation is hard to understand.
4. The right documentation cannot be found when needed.
5. There is too much printed material about the computer and its programs.
6. There are no programs to help the classroom learning.
7. "I only use one program for all my work since it is the one I understand."
8. There is a need for programs to support classroom training.
9. Each person had a personal model for the "perfect" computer support for operations research.

The computer's role was perceived by most faculty and students to be either the solution to all the problems or the cause of all the analyst's problems. The role of the computer has to be somewhere

in between, so the following hypothesis comes from these early observations of the computer's role. The computer and operations research have a synergistic relationship so that advances in either area often produce advances in the other without further effort. Further, as this relationship is understood, it may become possible to define the 'ideal' model of computer support for the operations research analyst.

Simply because most of the mathematical methods and models used in operations research are implemented with a computer, we can say that there is a relationship between operations research and the computer. However a more exact definition of this relationship is necessary to determine how to train and use both operations research analysts and computer specialists. The first place to look for this definition is in history.

There is very little written on the historical background of how operations research and computer science came together. A possible reason for the lack of documentation is the relative youth of both fields. Both operations research and the modern electronic computer are products of World War II, or seem to be at first look. Another possible reason for the lack of documentation is simply that there are few people trained in both operations research and computer science. And in this small group, only a very few are willing to research and write on history when there are more pressing problems around them.

There is a known value to history. It provides for us a perspective for our view of the present. And in operations research and computer science an awareness of past efforts provides an analyst with an appreciation of other possible ways to approach his specific problems.

Statement of the Problem

The preceding information leads to the following fourpart statement of the problem.

First there is a need for a model of the relationship between the computer and operations research. And this model needs to be narrowed and refined until we arrive at a more specific model describing the relationship between the computer and operations research in the education of operations research analysts. The model needs to be based upon historical facts, current operations research education, and future projected operations research needs.

Second, the model of computer support for operations research education should be specifically applied to AFIT and the GOR program. From this application of the model to AFIT, both strengths and weaknesses can be detected. And items which need to be strengthened can be identified and scheduled for improvement.

Third, for the AFIT GOR student there is a need for a handbook/ compendium specifically concerned with the computer resources available for the analysis of operations research type problems. It should be brief and helpful, almost a guide book, since for most of the resources which are available there is an excess of written information once you can find it.

Fourth, since problem formulation and selection of the 'best' computer algorithm is such a key area for the analyst, the handbook could be more useful if it included a method for selection of the 'best' algorithm to solve a specific given problem.

Objectives

The objective of the thesis is to survey and extend the AFIT computer resources for the operations research discipline. As this objective is quite broad the following supporting objectives state the scope and limit of the thesis effort.

1. Develop a historical perspective of the nature of the relationship between operations research and computer science. This provides a foundation for the model of computer support for operations research.
2. Develop a model for computer support in terms of needs and opportunities for use in the operations research curriculum at AFIT.
3. Determine the computer support presently available for operations research at AFIT and evaluate it against the model.
4. Determine the greatest need for algorithms in AFIT operations research curriculum and attempt to extend the AFIT computer resources at this point.
5. Organize and document the resulting operations research computer support resources in a 'users manual' for AFIT GOR students.
6. Develop a heuristic approach to the problem of selection of the 'best method' of solving operations research problems.

The thesis effort will be restricted to those algorithms and

operations research methods which are currently taught in the graduate operations research programs at AFIT. Any new programming effort will be designed to help the user learn a solution method or understand how an algorithm works.

II. METHODOLOGY

Data Requirements

The data gathering phase of this thesis is primarily a literature search of the various libraries available to AFIT. It will include the following procedures:

1. Examine the AFIT curriculum and other curriculums in operations research and determine what computer support has been used or might be used in the near future.
2. Review the last two years graduate operations research and systems management theses and obtain the actual computer resources used in thesis preparation.
3. Survey the various libraries which are at AFIT to find the computer resources which would support operations research applications and to locate the descriptions of the various algorithms used in operations research applications at AFIT.
4. Search the literature for historical information concerning the relationship between operations research and computer science.
5. Collect information on problem formulation and selection of 'best algorithm'.

Treatment of Data and Analysis

The analysis and application of the data will be as follows:

1. The historical data will be compiled into a time line to show the interrelationship between operations research and computer science.

2. Based on the historical relationship a model will be proposed to explain the interaction between operations research and computer science at the graduate education level.

3. Using the model, areas of the AFIT computer resources which need additional programming effort will be determined and one or more will be selected for additional programming.

4. The information about the AFIT computer resources which support operations research will be compiled into a handbook/compenidum.

5. A decision methodology for solution method selection will be attempted based upon the types of problems found in the field of operations research.

Order of Presentation

The information which follows in this thesis is presented in the following order:

1. A discussion of the relationship between operations research and computer science as based upon the historical literature search.

2. A description of the model to describe operations research and computer science at the graduate level and a discussion of AFIT against that model.

3. A discussion of the user handbook and how the information contained in it can be used.

4. A brief discussion of the programming efforts associated with this thesis clearly pointing out what was accomplished and what are the logical next extensions.

5. A discussion of the 'best algorithm' selection methodology

There will be several appendices attached to the thesis. They include:

1. Interview questions and the associated cover letter.
2. Operations research and computer timeline and bibliography.
3. GOR Computer Support User's Guide
4. List of available operations research algorithms with bibliography references.

III. HISTORICAL RELATIONSHIP BETWEEN OPERATIONS RESEARCH AND COMPUTERS

Introduction

It is often said that those who do not know history are doomed to repeat it and the operations research analyst is not an exception to this. The historical relationship between operations research and the computer can provide additional perspective on the present. As the richness of the historical backgrounds for operations research and computer science was examined the different phases of the relationship between them unfolded. In this chapter the brief discussions of the development of operations research, the development of the computer, the computer's effect upon operations research, operations research's effect upon the computer, and the synergistic relationship of operations research and the computer will just use brief extracts from the time line and bibliography contained in Appendix B.

Development of Operations Research

It was not until World War II that the term 'operations research' or 'operational research' was coined. It was used to describe a form of scientific problem solving as applied to operational problems in a war time environment (Ref 39). Yet there are instances of scientific problem solving in the operational environment much earlier.

There is Archimedes, often considered the greatest mathematician of antiquity, who at Syracuse in 215 B.C. analyzed the problem of the Roman seige and provided operational solutions which kept the Romans at bay until 212 B.C. He improved upon the existing catapults and

developed a 'burning glass' which kept the Romans from approaching the city (Ref 15). Archimedes was killed when the city was taken by the Romans storming the walls.

In the 1700's, the Marquis de Vaubon, Louis XIV's Marshal of France, throughout his entire career applied the scientific method to operational situations and improved the use of existing weapons. It is of interest to note that the problems were not difficult to solve but the Marquis de Vaubon was often unsuccessful in getting the results of analysis implemented by others (Ref 45).

Charles Babbage wrote the book, On the Economy of Machinery and Manfactures, where he did a detailed analysis of the production of pins in England. Charles Babbage also analyzed the post office and suggested the penny-post as the most efficient method of pricing. His work was very much in the format of the current systems analysis efforts (Ref 11,38).

Fredrich William Lanchester and Thomas Edison both did analytical work during World War I and for the most part very few of their efforts were used by the civilian or military leadership (Ref 18). The methods of analysis and sophistication of the equations of conflict remained static until World War II. P.M.S Blackett with what was known as "Blackett's Circus" was the first to use the scientific method to analyze and solve operational problems and then to actually have them implemented on a regular basis. The radar and convoy problems are the two most famous (Ref 39).

The scientific method developed as it solved problems and had the solutions implemented. When the solutions are not implemented then the

methods for solution develop very slowly if at all.

Development of the Computer

It was during World War II that the modern electronic computer was finally developed; however there were attempts to build computers much earlier. It was Gottfried Wilhelm Liebniz that built a four-function mechanical calculator in 1694. This calculator is considered the first one of its kind to work correctly. Liebniz's purpose in building it was to assist the work of his father an accountant. In spite of his efforts the device was never successful commercially.

In 1812 Charles Babbage proposed the building of a difference machine which would be capable of automatically calculating tables. The motivation behind this machine was Babbage's horror at the number of errors in the hand-produced mathematical tables of his day. In 1834 Charles Babbage proposed an analytical engine which for all purposes would have been the mechanical equivalent of the electronic computer. During his lifetime neither machine was finished for many reasons, but primarily for the reason that there was no demand for the capabilities of the computer in 1834.

It was World War II and the need for ballistic tables in the United States Army which provided the motivation to build an electronic computer (Ref 32). The ENIAC System, proposed by J. Presper Eckert and John W. Mauchley, became the first electronic computer actually used.

The history of the development of the electronic computer illustrates the slow evolution of a device or invention when there is no demand for it. The computer is an invention which had to wait until

there was a need or problem serious enough to justify the costs necessary for its development.

The Computer's Effect upon Operations Research

When the types of operations research problems implemented upon the computer are examined, especially the early programming efforts it is observed that the current ability of the computer will affect the type and magnitude of the problems attempted.

There are four areas where the computer has had the strongest effect upon operations research. Three of these can be considered inherent characteristics of the computer and one of them is a result of these characteristics.

First the speed of the electronic computer affected the type of problems attempted. At RAND one of their early computers was used to perform ballistic missile calculations and literally it did in minutes what before had required months to complete by hand (Ref 24).

Second the accuracy of the computer has greatly affected the type of problems implemented. It is recognized that the computer is limited by the accuracy of the programs entered into it; however it normally does not make internal math mistakes as humans often do. As an illustration, at RAND in the same set of missile calculations it was discovered that the previous sets of ballistic tables were incorrect due to errors entered into in the "by hand" calculations. The effect of the computer's accuracy and speed upon the operations research type of problems can be best appreciated by any analyst who

has to do any matrix mathematics even with two by two matrices. It is very difficult to do the necessary arithmetical manipulations by hand without error and maintain any required level of speed.

Third, the storage capacity of the computer has affected the problems attempted. Because the computer can store the intermediate values in a calculation the analyst discovers that the problems can often be described in terms of the original data and the final desired answers. The characteristics of the electronic computer provide the capabilities in terms of speed, accuracy, and storage capacity to go from the original data to the final answer when correctly programmed.

Fourth, the development of Monte Carlo methods which were a direct result of the unique characteristics of the computer became the basis for computer aided simulation. Simulation with Monte Carlo methods has become one of the most important tools for the operations research analyst (Ref 39).

The computer's effect upon operations research and many other fields is that the current abilities of the computers available affect the type and magnitude of the problems attempted.

Operations Research's Effect upon the Computer

Like the development of the scientific method, operations research is very sensitive to the present needs. The types of needs will affect the types of solution methods which are developed and these in turn have affected the development of the computer.

For example, in World War II the problem of cryptoanalysis and the associated mathematical methods forced the development of EDSAC

at Cambridge (Ref 44). In the United States the problems in cryptoanalysis and in intelligence in general caused the development of new computers. Samuel Snyder in "Influence of U.S. Cryptographic Organization on the Digital Computer Industry" clearly shows the major technological results (Ref 44). For example, the first use of drum memory in the U.S., first completely transistorized computer in the U.S., and the first completely automated tape library in the U.S. were all developed for the National Security Agency.

The need for military simulations has affected the development of the computer. The need to do extensive simulations emphasized the need for faster and more efficient machines. An early use of the computer for simulation was Dr. Enrico Fermi's extensive use of Monte Carlo techniques in simulations while developing nuclear weapons (Ref 39). Myren Tribus in his article, "Observations on Computer Simulation in the Civilian Concerns of Government", commented on how simulation was made practical by the abilities of the modern computer (Ref 48). He also suggested that the future development and use of the computer would be affected by the use of simulation by decision makers. The very real affect of simulation upon the computer industry can be seen by the current use of simulation in the planning of the new computer systems. An example of this is in Richard Brice and J. C. Browne's article in the August 1978 issue of <u>The Communication of the ACM</u>. The article is devoted to the use of simulation to develop scheduling systems for multiprogrammed multiprocessor computer systems (Ref 6:78).

The work of George Dantzig with the Scientific Computation of Optimum Programs studies dealt with the computer implementation of

linear programming systems and numerical analysis. A major result was the impetus to develop computers which could handle large data structures and that were faster in doing mathematical computations. The CDC 6600 family of computers and the IBM 360 series are just two of many resulting from the demand for speed and size.

Dr. George Dantzig's work is a good example of the effect that operations research has upon the computer. The development of the linear model and in particular the simplex method (Ref 17) generated a need for a computer which could actually solve this type of problem.

In summary, one of the effects that operations research had upon the computer is that the types of problems which were being formulated due to the new analytical tools produced a demand for computer systems capable of solving them.

<u>The Synergistic Relationship of Operations Research and the Computer</u>

Operations research and computer science are in a synergistic relationship where developments in one field cause more developments in the other field. This current relationship could be considered cylical in nature with the following cycle:

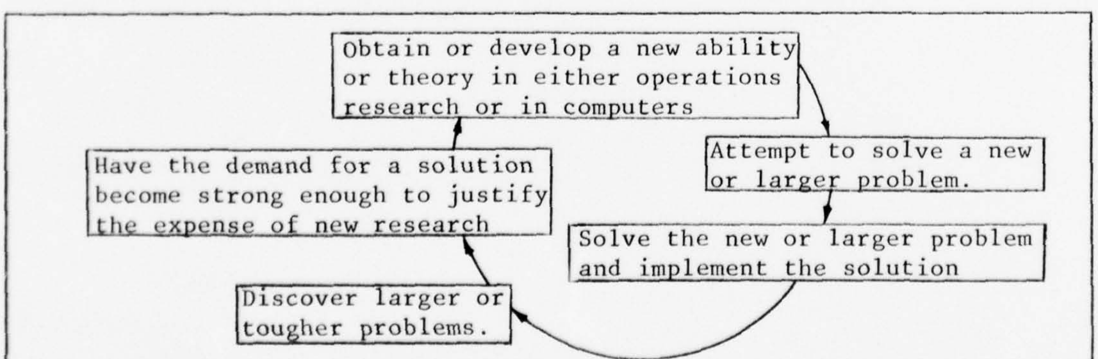

Figure 1. Operations Research and Computer Science Cycle of Development

In the early years of the computer and operations research it was seen by those involved that both fields were interrelated and that developments in one would affect the other. Dr. J. von Neumann wrote the following in 1951:

> We can now make computing so much more efficient, fast, and flexible that it should be possible to use the new computers to supply the needed heuristic hints. This should ultimately lead to important analytical insights. (Ref 20:297)

Along with Dr. J. von Neumann, who is one of the early innovators in both operations research and computer science, L. J. Comrie wrote in 1946, "If the machine is to justify its existence, it must be used to explore fields in which the numerical labor has so far been prohibitive" (Ref 20:113).

This fact is still recognized by the current researchers in these fields. E. S. Buffa wrote in his book, "Today, however, the computer has made possible new quasi-analytic and heuristic search techniques" (Ref 8:102). Dr. Billy E. Gillett made this current relationship very clear in his book. In the concluding portion of his introductory chapter it is stated, "Of course, the concurrent development of the digital computer is credited with the rapid progress of OR in this country" (Ref 19:2).

Conclusion

Both the operations research analyst and the computer science specialist could benefit from a historical perspective of the past development of both fields. Especially would the operations research analyst benefit since without the computer there are very few problems

of any magnitude which would be attempted today. Dr. Phillip Morse voiced this in the book Operations Research for Public Systems, 1967.

> When dealing with large and complex systems, the operations research group often involves the assistance of a high-speed computing machine. In many cases the operation is too complicated to be able to be expressed in a system of equations which can be solved with paper and pencil. (Ref 35:3)

In 1974, in the first issue of Computers and Operations Research, Joseph H. Engel focused very clearly the key lessons taught by history about the relationship between the computer and operations research.

> To return to my main theme, we may now see how computers enter the picture. Computers are a powerful tool to be used by Operation Researchers or Systems Engineers in solving important societal problems. We can't begin to tackle complex problems without computers. You all know the reasons: speed, accuracy, and the ability to process huge quantities of data. (Ref 14:6)

He made several important points. First that the purpose of operations research is to solve problems and second, that the computer is needed to solve many of these problems which are too complex to attempt without it.

Every operations research analyst probably will have contact with a computer in his career of problem solving. The analyst's effectiveness could be enhanced by an awareness of the computer and its abilities to solve problems in the operations research field.

IV. MODEL OF COMPUTER SUPPORT FOR GRADUATE OPERATIONS RESEARCH EDUCATION

Introduction

The purpose of this chapter is to present a verbal model of the computer support for graduate operations research education. The model needs to have both historical and contemporary justification for its existence. This will be given in the first three sections where the areas of interest in operations research, the computer usage in graduate operations research programs, and the availability of computer algorithms are discussed. The model itself will then be developed by presenting a series of models which start very general and then progressively specify the exact environment of the computer support for graduate operations research education model. Finally, the verbal model of computer support for graduate operations research education will be transformed into a checklist to aid in evaluating the AFIT GOR computer support.

A model of computer support for operations research is needed for many reasons. First, the model could assist in the planning of future acquisition of computer resources. Second, the model may have implications for the structure of the academic curriculum itself. And third, a model may provide another tool to help manage the computer resources supporting the graduate operations research program.

Operations Research Areas of Interest

Some authors divide operations research according to the steps

used in applying operations research to individual projects. The classical, often stated, operations research process is the following:

"1. Formulate the problem
2. Construct a mathematical model
3. Derive a solution from the model
4. Test the model and the solution derived from it
5. Establish controls over the solution
6. Put the solution to work" (Ref 46:766)

In the same article T. Bernard Tate sees "five essential ingredients" in operations research.

"1. Maintaining good client relations
2. Generating many alternatives
3. Conducting approximate appraisals
4. Modelling rigorously
5. Managing effectively" (Ref 46:770)

He goes on to subdivide operations research projects into 78 different steps. This viewpoint of operations research as a process is one way to identify the areas of interest in operations research.

The other common division of operations research is that of the various tools and techniques used in operations research. This type of division is found in many operations research textbooks. The following table summarizes the amount of space devoted to different topics in three common textbooks and one reference book. The numbers represent a percentage of the tutorial portion of the book.

TABLE I

Distribution of Space used per Topic

As a Percentage of the Text.

Topic	Text: Hillier Ref 8	Budnick Ref 60	Gillett Ref 84	Eiselt Ref 80
Linear Programming	32.5	27.5	10.5	21
Pert/CPM	4.5	7	3	27.5
Dynamic Programming	4.5	5	10	
Game Theory	3		5	10
Statistics	10.5		5.5	1
Queuing	13	6.5	7.5	2.5
Inventory	8.5	6	10	3.5
Markov Processes	6	6	5	
Reliability	2.5			
Decision Analysis	3	6	3	3
Simulation	5.5	8.5	5.5	
Integer Programming	3.5	5	19.5	13.5
Nonlinear Programming	2	5		8
Ethics	1			
Classical Optimization		12.5		
Heuristics		4		5.5
Sequencing			5.5	4.5
Regression			10	
Misc.		1		
	100%	100%	100%	100%

Other textbooks show similar topics in their coverage of operations research. Two observations are made from the table. First, linear programming is a large portion of each text and if the integer programming is included with linear programming then 30 percent or more of each text is devoted to this topic. There may be a historical reason for this in that linear programming as Dr. George Dantzig formulated it in 1947 was intended to be a very practical tool for the manager. It has been widely applied and therefore is accorded an important place in the textbooks.

As the undergraduate and graduate operations research programs divide operations research it appears from the catalog and course descriptions that most divisions are similar to the divisions used in the textbooks. George A. Johnson, of the University of Connecticut described this usual approach as "integration of tools topics" and he contrasted this with his proposal for "integration of tools concepts with functional area topics" (Ref 28:786). In his proposed curriculum those courses teaching the use of techniques would include application of the techniques to the same set of case studies. Each technique may be applied to multiple cases studies. Interesting enough, Bernard Tate at the London University uses this technique to organize the individual courses he teaches (Ref 46:778).

The actual content of the courses taught at the different schools with operations research courses has not been given a thorough analysis. In this thesis the weaknesses of using the school catalogs to determine course content was recognized. It was assumed that AFIT GOR is a typical curriculum and its division of operations research was examined.

In the AFIT resident programs which are operations research related, we see the following division in instructional content (Ref 3). The following table only includes the graduate level courses because the actual undergraduate courses taken vary more depending upon student training prior to AFIT.

TABLE II

Graduate Quarter Hours of Instruction in AFIT Programs

	Graduate Program		
Academic Area	Operations Research	Systems Management	Strategic and Tactical Sciences
Mathematics	9	6	10
Accounting	3	6	
Management	3	16	
Economics	12	6	
OR Techniques	15	6	16
Thesis	12	12	12
Writing	2	2	2
Weapons			37

It is observed that there are no graduate level history or computer science courses in any of the programs.

The manner in which the ultimate users of operations research analysts divide the topics of operations research is not well documented. There are several studies available. First, the E. Turban Study, summarized in the first chapter of Hillier and Lieberman's text, concluded that 73 percent of the frequency of use was in statistical analysis, simulation, and linear programming (Ref 25:6). Second,

from "The Utility of Certain Curriculum Topics to Operations Research Practitioners" the authors report that 59 percent of the utility is in the same three general techniques (Ref 42:744). Third, in 1977, Thad B. Green and others from Mississippi State University did a survey of quantitative techniques used in production/operations management. While this was not exactly intended to evaluate all techniques usually considered operations research techniques, similar results were seen. Since the data was collected and analyzed in a different fashion the same percentages are not available. However, seven topics which were determined to receive moderate or heavier usage better than half of the time were time series analysis, inventory models, statistical sampling, regression and correlation, linear programming, network analysis, and analysis of variance (Ref 22:671).

Computer Usage in Graduate Operations Research Programs

There are two reasons for the use of the computer in graduate operations research education. First, historically the solution methods have developed only as the computer's abilities were enhanced. If the timeline in Appendix B is examined, especially in the years after World War II, it is observed that the acceleration of computer development was paralleled by the rapid expansion of operations research techniques. This was especially true as both disciplines were actually applied to real world problems. This leads to the second reason. Most current problems solved with the techniques taught in operations research require the computer's assistance. The computer has become a valuable tool for the operations research analyst.

Different operations research graduate programs in different universities use the computer in varying amounts. Different college catalogs provided an overview of this. For example, Stanford University described their operations research facility as having dedicated remote terminals with FORTRAN being the main language used. Interesting though, the Stanford University catalog implies that actual programming is only done by doctoral students and that the master's level student is only a casual user of the computer.

In other schools the following computer usages were noted from the college catalogs. The Illinois Institute of Technology uses GPSS for simulation and FORTRAN for other applications such as linear programming and inventory problems. The Georgia Institute of Technology catalog describes much the same usage of the computer.

At AFIT the curricula, facilities, and personnel were available to be examined personally. In an interview of faculty members, they were asked which computer resources are used in the academic courses. Faculty members were also asked which computer resources they have used in personal research projects. The interview questions were very subjective in nature and a copy of the questions used is in Appendix A. Theses from Graduate Operations Research and Graduate Systems Management (GSM) for 1976 through 1977 were also examined to determine which resources were used by those students. In addition the author of this thesis was exposed personally to various computer resources during academic curriculum of the Graduate Operations Research Program, GOR-78D. This information is summarized in the following table.

TABLE III

Use of AFIT Computer Resources

Computer Resource	Academic Courses (number of courses)	Faculty Research (number of instructors)*	GOR/GSM Theses (number of theses)**	GOR-78D Curriculum (X if used)
	Area Computer Resource Used In			
FORTRAN	1	4	10	X
SPSS	4	3	6	X
OMNITAB	2	3	4	X
DYNAMO	2	2	0	X
SIMSCRIPT	1	1	3	X
LPKODE	2	1	0	X
IMSL	1	1	0	X
BDM	1	0	0	
GPSS	1	0	1	
BASIC	1	1	0	
Q-GERT	1			X

* Total number of instructors interviewed was 11.

** Total number of Theses reviewed was 47.

In addition to the resources on this table some members of GOR-78D have used additional computer resources available on the CYBER system.

All of the preceding computer resources can be considered programming languages for the GOR student, except for LPKODE, BDM, and IMSL which are precompiled programs or subroutines which are used to solve

certain specific problem types. LPKODE solves small linear programming problems. IMSL and BDM contain mathematical routines for statistical and optimization applications. The latter two require a certain level of FORTRAN programming proficiency to use successfully.

AFIT has many computer resources which could be considered as supporting the operations research program. They range from hardware such as Calcomp, the Zeta Plotter, INTERCOM terminals, and batch facilities to additional software such as the packages just discussed.

Summary of Computer Algorithms Available

When the question is asked, "What operations research computer-supported algorithms are available?", then the correct answer is, "How large is your budget?". In a real sense you can purchase any specific ability that you want if you are willing to pay the cost.

The algorithms which are common usually include linear programming packages, regression analysis often with very powerful statistical tests included, and statistical packages which do a variety of tests. These algorithms tend to be very general in approach and can be applied to a variety of problems. There are many areas of operations research where the computer algorithms which have been written only solve a very narrow class of problems. Examples of this are simulation programs where each different problem is often a new program. In Appendix D is a list of algorithms with their location in the literature which were considered to possibly be useful in operations research graduate education.

Development of the Model's Environment

In order to focus upon a narrow model it is instructive to first see the perspective in the larger models which conceptually surround it. The operations research analyst's relationship to operations research and computer science is pictured by the first model.

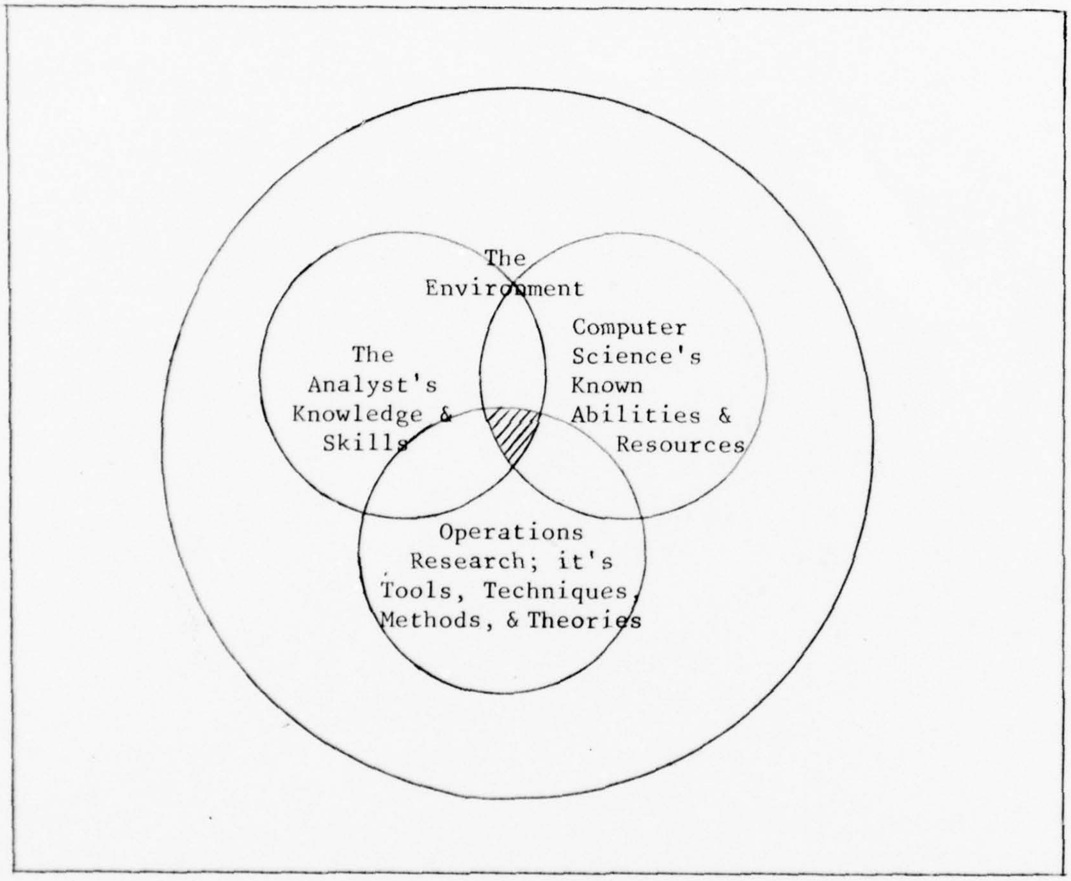

Figure 2. The Environment Model

In this model the environment includes everything external to the analyst, computer science, and operations research. The analyst's circle includes all of the training, background, and skills and is

constantly expanding. This expansion will continue as long as the analyst is alive since all of life's experiences result in gaining information about the environment. The circle with computer science is also expanding as the experts in that filed add to the known store of knowledge. This circle also includes developments in the area of hardware. The last circle is for operations research and it also is expanding as new tools, techniques, and theories are developed.

Each of the circles intersects with the other two circles. An example is SIMSCRIPT which is both a programming language and a tool for operations research in simulation. Where the analyst intersects with the other two circles visually describes the area of operations research or computer science knowledge that the analyst has mastered.

The portion of this model in which we are most interested is the shaded area where the analyst, computer, and operations research intersect. While this has been drawn as a Venn Diagram it must be realized that each of the individual boundaries is dynamic and constantly changes as the analyst, computer science, and/or operations research grow and develop.

Since operations research depends upon the computer, the following variations of the above model due to an analyst's training could be undesirable.

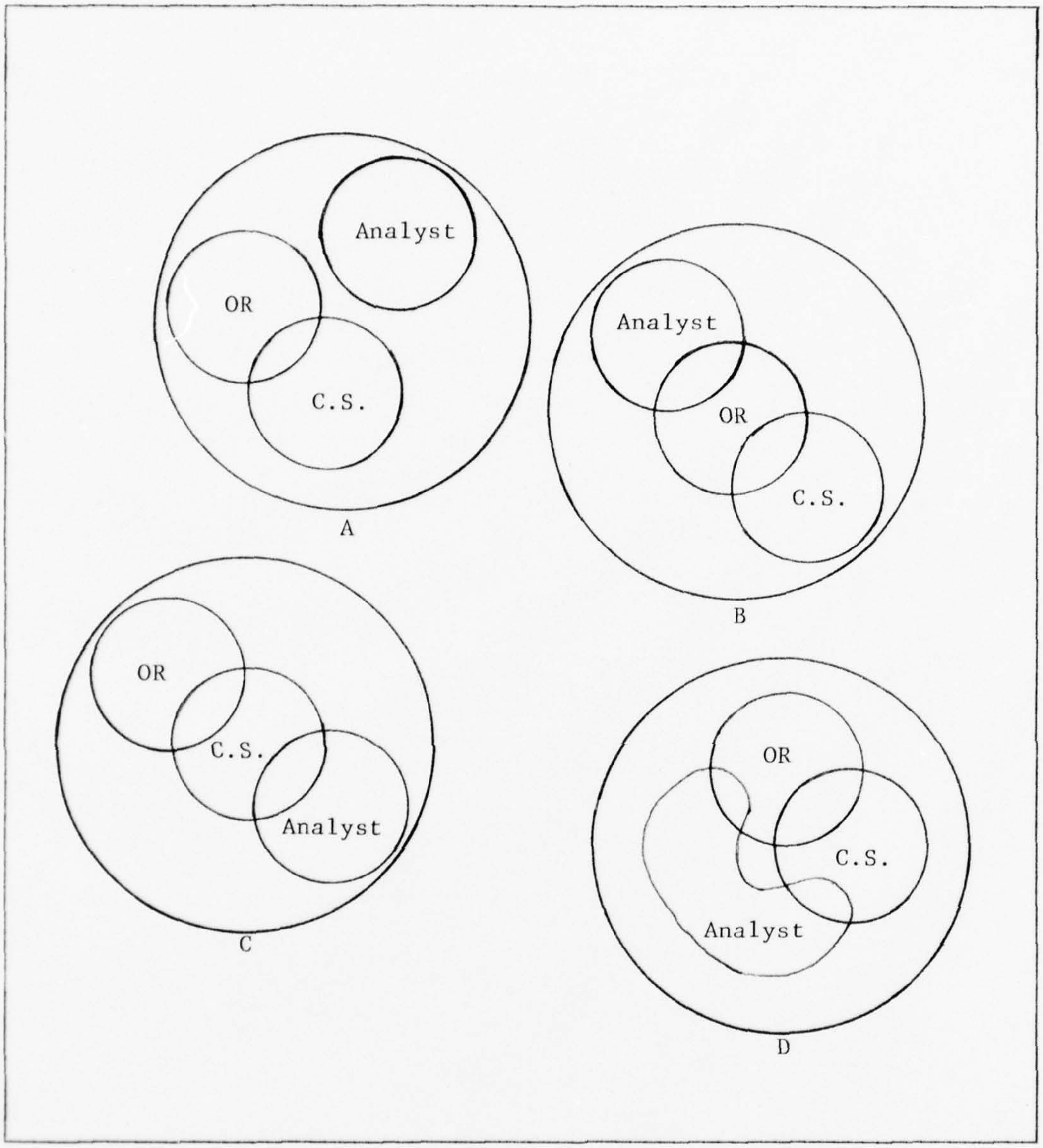

Figure 3. Variations of Environment Model

In figure A the analyst has neither operations research (OR) or computer science (C.S.) available to him. This is clearly undesirable. However Figures 3-B and 3-C may be more common and they represent the extremes of approaching the computer and operations research in analysts.

Figure C is more properly the computer specialist who becomes an analyst without any operations research training. Figure D is also undesirable. It is more difficult to spot since the analyst is conversant with both computer science and operations research. Yet, without the overlap of the areas of knowledge, any analysis is going to be done using either computer skills or operations research skills but not both. The preceding figures are strongly idealized, but they point out the importance of the education system in producing the desired abilities in the analyst.

This second model may help show the role of graduate or training in the overall educational environment. It is adapted from J.J. McDonald's article in the 1977 Operations Research Quarterly, Vol. 28, 3,ii. (Ref 33:617).

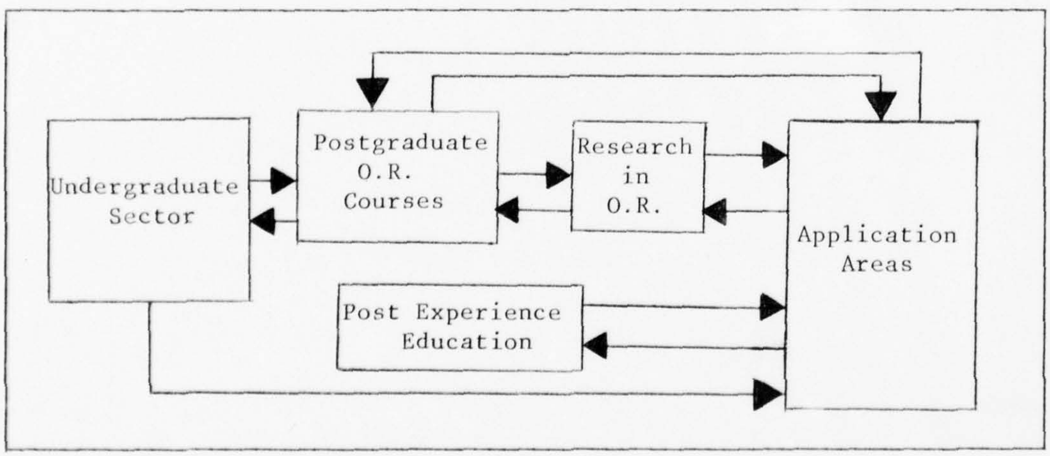

Figure 4. The Present Educational Structure

He discusses the flows between the educational parts of his model. He notes that the bulk of current operations research education is currently done at the postgraduate and post-experience levels.

The last model helps define the role of computer support for operations research graduate education. Computer support is shown with the other factors supporting graduate operations research.

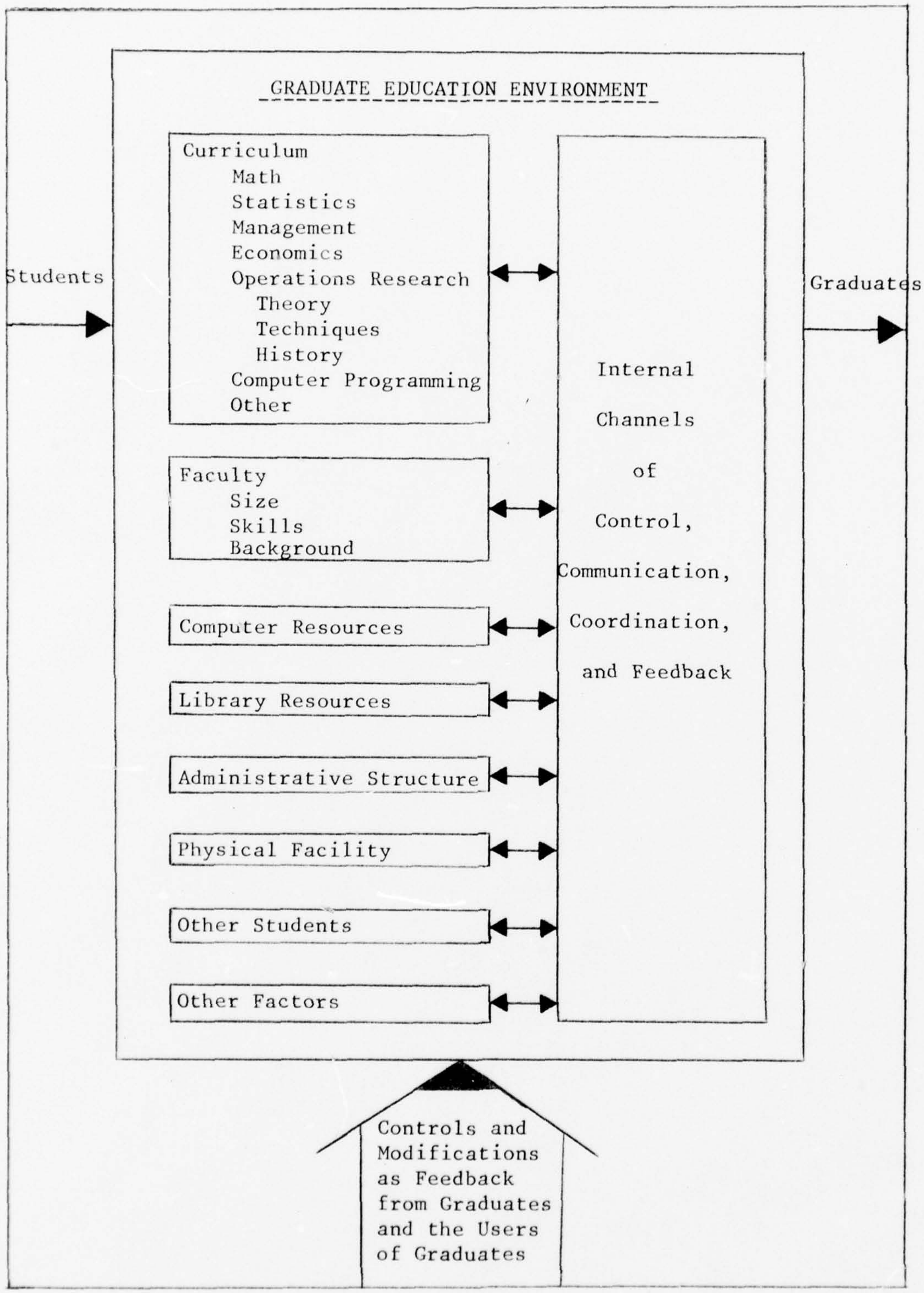

Figure 5. Graduate Operations Research Education

The role that computer resources have in the graduate operations research education depends upon internal and external forces. In this medel each of the factors has the internal channel of control, communication, coordination, and feedback providing input and output of information about its role. We can speculate that the strongest factors in the internal channel are curriculum and faculty. Internal factors will be partially responsible for defining the role that computer resources will have in the graduate operations research program.

The external forces act upon all of the factors of the graduate education environment. The quality of the students, especially with regard to prior computer experience, will have definite impact upon the computer support for graduate operations research educations. Also the feedback from graduates and their supervisors will help define the role each of the factors in the graduate education environment, including computer support.

This last model will focus upon computer support for graduate operations research education. It will be presented in an outline format. There will be a short explanation of key or potentially confusing entries in the outline. The structure of this model is an attempt to define the set of items which belong to the model. The exact interrelationships between entries in this model will not be explored deeply.

The outline is divided into two main sections; potential support and actual support. Potential support includes all of the software, hardware, personnel, and plans which could be used to support operations research. An item is identified as potential support if it could be used in the training of an operations research analyst. Being identified as potential

support is descriptive and not prescriptive. Actual support are the items which are actually used by the graduate operations research education program.

Model of Computer Support for Graduate Operations Research Education

I. Potential Support

A. Software -- these are the programs which make the computer work for the different users.

1. Operating System
-- these are the programs which assist the user in running programs and make many of the common jobs which use the computer easy to do. Examples include the Cyber Control Language, UPDATE, COPY utilities, the EDITOR on INTERCOM, and others.

2. High Level Languages
-- these are the programs which allow the user to write application programs in the languages such as FORTRAN or BASIC.

3. Applications Programs
-- these are programs or subroutines which are ready to run as soon as the program is given the correct data to begin. An example of this is any of the IMSL routines.

4. Documentation of Software and Textbooks
-- these are handouts, guides, etc., which explain the operating system, high level languages, and application programs so that the user is able to understand the programs needed to solve each problem solved using the computer.

B. Hardware -- these include the all of the things involved with the computer which are considered 'permanent'.

1. Computer
-- this is the actual machine available for use.

a. Speed
-- this is how fast the computer does calculations and how fast the user normally gets a response from the computer either from a batch job returned or from a time-sharing terminal with interactive responses.

b. Accuracy
   -- this is a measure of how many significant digits of data normally can be stored.

c. Size of the System
   -- this is the number of individuals or organizations that use the computer.

2. Peripheral Devices
   -- these are the items connected to the computer which in general allow it to communicate with the user.

a. Classical Input/Output
   -- these are the card reader, line printer, card punch, and paper tape reader and punch.

b. Graphical Devices
   -- these are the plotters which use pen on paper such as Calcomp, the terminals of varying degrees of sophistication, and the microfilm plotters.

c. Remote Terminals
   -- these are the consoles which allow the user to have timesharing access to the computer with other users.

3. Mass Storage
   -- these include the different devices which can be used to store large amounts of data. An example is magnetic tape.

a. Size
   -- this is a measure of how much can be stored on the different mass storage devices.

b. Speed
   -- this is a measure of how fast information which has been stored in the mass storage device can be recalled.

c. Accuracy
   -- this is a measure of how reliable the different mass storage mediums are.

d. Ease of Use
   -- this is a subjective measure of how simple it is for the user to use the different mass storage devices in an individual program application.

4. Physical Facility
   -- this is the place where the computer is located and the places where the users interact with the computer system.

a. Location

-- this is some measure of how convenient the computers location is for the user.

b. Size

-- this is a measure of how much room the computer and the user are provided.

c. Work and Study Space

-- this is a measure of how much space is available near or at the computer center for the work and study which will result from using the computer in operations research.

C. Personnel-- they include all the personnel associated with AFIT that are involved with the computer. They do not have to be assigned to AFIT.

1. Computer Experts

-- they are individuals with the specific knowledge and training to understand the different computer resources. They are primarily experts in the operating systems, high level languages, and hardware capabilities.

2. Operations Research Applications Experts

-- they are individuals with the specific knowledge about the different applications programs used in the graduate operations research education program. Their abilities may be very specific, knowing only about the application of a single computer resource to an operations research problem.

3. Interface Experts

-- they are either computer specialists with training in operations research or operations research analysts who have a thorough understanding of the computer resources. Their role is that of being able to communicate with both the computer specialist and with the operations research specialist.

D. Plans -- these include the results of planning for the operations research graduate program, the management of the computer resources, and the relationships between the computer resources and operations research. These include present operating plans and future plans.

1. Computer

-- these areas of planning include management, support, acquisition, and removal of items in one of the following categories.

a. Software

b. Hardware

c. Personnel

d. Plans

2. Curriculum and Computer

-- these are the plans that detail how specific computer resources will be used to support academic objectives.

a. Operating Systems
-- these plans detail which operating system programs the GOR student should be trained to use.

b. Application Programs
-- these plans will detail which application programs the GOR student should be trained to use. The GOR should also be able to interpret the results of that application program.

c. High Level Languages
-- these plans will detail which high level languages the GOR student should learn. The plans will also specify at what point in the program the language is to be learned and then applied to operations research problems.

d. Documentation
-- these plans will detail how the supporting documentation for the computer resources supporting operations research is to be maintained. This has to include some method of monitoring what documentation is maintained in the AFIT library.

e. Needed Abilities or Programs
-- these plans will detail how the needed computer resources will be obtained. These plans should also substantiate the need for the new resources.

f. Relationships Between Academic Courses
-- these plans will detail how the computer resources learned and used in one course of the curriculum will aid the learning objectives in another course of the curriculum. These plans will show how the use of the computer resources in the graduate operations research program is related to the progress of the operations research curriculum program during the 18 months.

II. Actual Support

-- this is a description of how the potential support is actually used.

A. Faculty -- these are the AFIT instructors who teach any of the required courses for the Graduate Operations Research Program.

1. Training

-- this is the training actually given faculty members on the computer resources which support operations research.

2. Use of Computer Support

-- this is the actual use the faculty members make of the computer resources supporting operations research. This includes both classroom and personal research.

3. Evaluation

-- this is the actual measurement of how well the training in and use of computer support by the faculty correlates to the plans defined in the potential section. Comment: Having no plan and doing no evaluation is a type of planning and evaluation.

B. Students -- these are the students assigned to the Graduate Operations Research Program at AFIT.

1. Training

-- this is the training actually given GOR students about the computer resources supporting operations research.

2. Use of Computer Support

-- this is the actual use the GOR students make of the computer resources supporting operations research. This includes both classroom assignments and thesis research.

3. Evaluation

-- this is the actual measurement of how well the training in and use of computer support by the GOR students correlates to the plans defined in the potential section. Also this includes the measurement of how well the AFIT training supports the users of AFIT graduates. Comment: Having no plan and doing no evaluation is a type of planning and evaluation.

Evaluation of AFIT GOR's Computer Support

This evaluation will be done using a checklist based directly upon the model developed in the previous section. The information used to measure AFIT GOR's computer support is very subjective. This information comes from the faculty interviews and from personal experience as the only member of GOR-78D with an undergraduate degree in computer science. During the preparation of this thesis the suggestions, complaints, and comments of other students became another source of subjective information on present computer support. There is a copy of this checklist in Appendix F.

Each item of the checklist is given one of three subjective ratings:

1. Not rated-for those items either not evaluated or for which there was no data.
2. Positive factor-for those items which seemed to provide proper support for graduate operations research education.
3. Negative factor-for those items which did not seem to provide proper support for graduate operations research education.

After each rating is the source of the data used, and if more comments are needed then a footnote following the checklist is used.

TABLE IV

Checklist for Evaluating Computer Support for Graduate Operations Research Education

Item or Section	Not Rated	Positive Factor	Negative Factor	Data Source	Footnote Reference
I. Potential Support					
A. Software					
1. Operating Systems		X		Students Faculty	
2. High Level Languages		X		Students Faculty	
3. Applications Programs			X	Faculty	1
4. Documentation			X	Students Faculty	2
B. Hardware					
1. Computer					
a. Speed			X	Students	3
b. Accuracy	X				
c. Size of System	X				
2. Peripheral Devices					
a. Classical Input/Output	X				
b. Graphical Devices	X				
c. Remote Terminals	X				

TABLE IV (cont)

Item or Section	Not Rated	Positive Factor	Negative Factor	Data Source	Footnote Reference
3. Mass Storage					
a. Size	X				
b. Speed	X				
c. Accuracy	X				
d. Ease of Use			X	Students Faculty	4
4. Physical Facility					
a. Location		X		Students	5
b. Size	X				
c. Work and Study Space			X	Students	6
C. Personnel					
1. Computer Experts	X				9
2. Operations Research Applications Experts	X				9
3. Interface Experts	X				9
D. Plans					
1. Computer					
a. Software	X				10
b. Hardware	X				10
c. Personnel	X				10
d. Plans	X				10

TABLE IV (cont)

Item or Section	Not Rated	Positive Factor	Negative Factor	Data Source	Footnote Reference
2. Curriculum & Computer					
a. Operating System	X				10
b. Application Programs	X				10
c. High Level Languages	X				10
d. Documentation	X				10
e. Needed Abilities or Programs	X				10
f. Relationships Between Academic Courses	X				10
II. Actual Support					
A. Faculty					
1. Training			X	Personal	7
2. Use of Computer Support	X				
3. Evaluation	X				
B. Students					
1. Training			X	Students Faculty	8
2. Use of Computer Support	X				
3. Evaluation	X				

Footnotes for Table IV

1. The need for linear programming algorithms at AFIT was expressed by several of the faculty members. It can be expanded to several different types of algorithms desired.

    a. Linear programming algorithms which support the classroom instruction.

    b. Linear programming algorithms which can handle very large problems.

   Also the faculty expressed a desire for an integer programming algorithm as well as other types of algorithms which would illustrate the solution of some of the classic operations research type of problems.

2. Some of the faculty desired more or better documentation. From the students point of view it was usually a problem of either not being able to find the documentation or not being able to use it.

3. This was a common student comment about the turnaround time for a submitted card deck. This subject alone would make an interesting research project.

4. The difficulty of using mass storage was expressed by both faculty and students. After further questioning it appeared to be more of a problem in education.

5. Having the computer terminals available in the academic building is very convenient.

6. Several students have expressed a desire for more work and study space to be available in key punch and computer terminal area.

7. In light of the relationship between operations research and the computer there should be some kind of a training program for showing the new faculty member the potential computer resources which support operations research at AFIT. This could be of value both in the classroom and in personal research.

8. Students desired more training in the following areas:

    a. Cyber Control Language and related systems commands.

    b. Mass storage and how to use it.

    c. Structured programming techniques.

    d. How to plan large data structures and how to use them.

9. Although there were some comments about the need for certain types of personnel, these blocks were not rated because the measure of what is correct was not definable. A graduate operations research program using any amount of computer resources needs all three types of personnel, but exactly what is the right amount has not been defined.

10. These blocks were not rated because no information was gathered about this item.

From the evaluation of AFIT GOR's computer support using the previous checklist two items were selected for further research. First, in Chapter V a guide will be discussed which may help the documentation problem. Second, in Chapter VI the need for application programs to solve linear programming problems is discussed.

V. AFIT OPERATIONS RESEARCH COMPUTER SUPPORT USER'S GUIDE

Introduction

From the evaluation of the AFIT computer support of operations research there was a perceived need for more or different documentation. In this chapter, the ideal user's guide to operations research computer support will be defined first. Then the limitations which the AFIT environment puts upon such a guide will be discussed. Finally the user's guide contained in Appendix C to this thesis will be described.

Ideal User's Guide

The ideal user's guide would contain complete documentation on all computer resources which support the graduate operations research program. All the information would be contained in a single volume which would be of readable size. The volume must contain the detail and technical preciseness necessary in a reference manual for advanced operations research applications of the computer support. The user's guide must also be easy to read and very straightforward for the novice user who has limited computer experience and has a simple application needing a quick solution.

It becomes clear that the ideal user's guide may have several mutually exclusive characteristics. It may be possible with future technology to achieve such a document with electronic assistance. However as long as the user's guide is limited to the printed page then there are limitations to developing a user's guide.

Limitations to Developing the User's Guide

The limitations to the development of a user's guide are due to

three factors: the data, the user, and the author.

The data limitation upon a user's guide is due to the large amount of documentation which must be analyzed and incorporated into a user's guide. In the AFIT engineering school computer room alone there are about eight feet of manuals on the system. There are over twenty thousand pages of material which must be searched for items which are classified as computer support for graduate operations research. Also there is additional documentation contained in the library, in textbooks used in various courses, in department and course handouts, and in the personal expertise of the computer support personnel. It would be a large project just to catalog all of the data sources without attempting to analyze the contents. Because of the volume of information, the duplicate, conflicting, or missing information will be hard to handle.

The user limitation upon the user's guide is due to the large differences between potential users. Different backgrounds and levels of abilities will mean that any specific level of detail or difficulty will be adequate only for a portion of the possible users. The graduate operations research student who has never used a computer may need different material from the experienced computer user. Also the potential user is less likely to read, study, or use a large document.

The author limitation upon the user's guide is due to the limited resources of a single individual or organization to both write and maintain the user's guide. The task of producing an extensive user's guide is put in perspective when it is realized that SPSS for example is maintained by a group of several schools under contract from the company distributing SPSS. SPSS is just one of many computer resources

which need to be documented in an operations research computer support guide. However the task of producing the initial version of a user's guide is just a beginning since the larger job will be the maintaining the document in a current and usable form.

The 'ideal user's guide' possibly is not feasible for even a large organization with nearly unlimited resources. It was recognized early that any attempt at an extensive document during this thesis effort was not possible. Several formats for organizing information were considered. The first would have been close to the ideal document. It would have included complete user's information with extended examples of the computer resources applied to sample problems. If each resource description and example would be limited to just ten pages then with the first one hundred resources the user's guide is one thousand pages in length.

The next proposed format for the user's guide considered using the computer for the collection, update, and display of the required information. Besides the difficulty of implementation, if the user's guide is only accessed by using the computer then possibly the GOR students who need the user's guide the most will use it the least.

The final format for the user's guide is a version of an annotated bibliography. It will be described and discussed in the next section.

Description of User's Guide

The User's Guide is similar in format to an annotated bibliography with the resources divided into five categories. The following is a brief description of each category.

1. System These items are large hardware and/or software systems which either by concept or usage can be considered a single resource. An example is the CYBER 74 INTERCOM system.
2. Operating System Resources These will be the programs which are specific to the computer system. An example is the Cyber Control Language.
3. General Languages These are the different high level languages which are available that could be important to the GOR student. An example is FORTRAN IV.
4. Problem Solving Languages These are specific high level languages or programs which are designed to solve only a narrow subset of problem types. An example is SPSS.
5. Application Programs These are programs which solve a specific problem. They are not a language but usually a program or procedure where the data is input and the final answer is output. An example is the IMSL package of subroutines.

Each of the five categories will become a section of the user's guide. This will allow for quick and easy addition or deletion of entries. The beginning of the guide will be an index for quick reference to any entry. Each specific entry will have three parts. First the resource name which will be the common name or title of the resource. Second, there will be a short description of the benefit that this resource could have for the GOR student. And finally, the third part will be a bibliography for the location of the documentation for this specific resource.

After the user's guide is complete, its distribution could include

all of the GOR, GSM, and GST students at AFIT. Copies could also be provided to the faculty and any other person doing operations research type of work at AFIT. The user's guide would also need to be reviewed regularly for currency and relevancy. This could be done by a survey of outgoing graduates to discover exactly what resources were used. Then this could be compared with the contents of the user's guide.

The user's guide will not be a large document, and attempts to make it a large comprehensive document should be resisted since the purpose of the user's guide is to be a sort of shopping list for computer resources. This will aid the operations researcher in choosing the 'best' resource.

VI. PROGRAMMING EFFORT

Needed Program

From the evaluation of the AFIT computer resources in Chapter IV, there was a need identified for several specific programs. One of these programs would be for a linear programming program which is easier to use than those available now. Also the related problem of solving integer programming problems with our resources was suggested by the faculty interviews. And finally interest was indicated in a series of programs designed to augment the classroom teaching of the different operations research techniques. In the following sections each of these subjects will be addressed.

Linear Programming Algorithms

The first problem was how to make linear programming easier for the GOR student. The present computer resource used by the GOR student for solving linear programming problems o- the computer is a program called LPKODE. It has been difficult to use due to changes in the program which were not documented in the handouts available for the user. Also some of the user information about LPKODE was not current regarding its capabilities. The history of LPKODE and its present capabilities were examined in order to update the documentation and make it easier for the GOR student to use.

LPKODE was brought to AFIT by an instructor about 10 years ago. The program was obtained because of the excellent sensitivity analysis built into the output of the program. LPKODE is still very useful

today for the same reason, especially for academic uses of linear programming in graduate operations research course assignments. LPKODE has been considered difficult to use because of three problems. First the input decks seem to be difficult to setup because of the use of fixed format. Second, LPKODE does not solve transportation, integer, and mixed integer problems as the present documentation implied. Third, LPKODE would only solve one linear programming problem at a time. This made multiple problems difficult to solve since they required multiple runs of the LPKODE program.

The first and second problems were handled at the same time. A new handout describing how to set up an LPKODE data deck was written using one of the problems out of Hillier and Lieberman's textbook as an example. The handout makes it very clear that the only type of problem that LPKODE will solve is the linear programming problem. It will not do integer or mixed integer programming problems. It was discovered that LPKODE has never been "fixed" to do those types of problems since it was brought to AFIT. The programming documentation for LPKODE does not exist and, since the program itself is without internal documentation, possibly the quickest way to obtain the ability to do integer and mixed integer problems is either to buy or write a new program.

The third problem with LPKODE was easy to change. The necessary GO TO statement and corrected exit from the program were added so now the user just puts the additional data decks after the first one in order to do multiple problems. Also, internal to the LPKODE source code, documentation was added describing exactly what was changed and why.

LPKODE Preprocessor

Because LPKODE has strict data formating rules, a program which would aid the user in setting up a linear programming problem was attempted. A sample run of the program is in Appendix G. The basic concept was to allow the user to describe the linear programming problem using an interactive program which would build the correct data deck for the LPKODE program.

The program is limited to 25 or fewer constraints and 25 or fewer variables. It works for setting up linear programming problems. However, many options of the program were not implemented because of time constraints.

There is available on the CREATE system a program called UHELP which assists the set up and execution of linear programming problems. It might be possible to have that program converted to run on the CYBER 74.

The concept of a preprocessor to help set up and execute problems will be discussed again in the last section of this chapter.

Integer Programming

Since LPKODE does not do integer or mixed integer programming problems it would be useful to have this capability. The CREATE system which is accessible from the School of Systems and Logistics has a program called INTLP which will solve small integer or mixed integer problems. It is limited to 14 or fewer variables and 16 or fewer constraints. The program is interactive with the user and requires a good knowledge of the different methods of solving integer programming problems. This program is documented in Time Sharing Applications Library Guide, Volume III - Industry by Honeywell Information Systems, Inc., (December 1972). Multiple copies of this and other Honeywell documentation are located in the School of Systems and Logistics library.

If AFIT desires to have integer or mixed integer programming algorithms available on the CYBER 74 system, then a program must be purchased or written. Control Data Corporation has available for purchase APEX III which solves linear programming problems. It can handle integer or mixed integer problems. It also can solve large problems (over 9000 variables). APEX III would require the user to learn a set of instructions for problem setup and solution.

The other choice is to have the integer/mixed integer programming program written at AFIT. There are several algorithms located in different textbooks which might simplify the programming effort. The different programs found during the literature search for this thesis are located in Appendix D. An integer/mixed integer algorithm contained in the book by Claude McMillan was loaded into the CYBER 74 (Ref 34:474-492). It worked for small problems. Since this algorithm is a branch

and bound technique it used large amounts of computer time for larger problems. However a useful algorithm for GOR student's needs would be one that solved integer programming problems with several methods.

Other Application Programs

There was some interest in programs which could aid the teaching of operations research techniques in the academic classroom. Again, a possible source for the algorithms is the current literature. Many of the programs found are for very specific or complex applications. Some of the programs or algorithms which were found are in Appendix D. These are the ones which appeared to be most useful for the GOR student.

Stanley J. Larimer's March 1978 AFIT thesis presented the development of the interactive computer program called TOTAL (Ref 29). While this program is designed for the electrical engineering graduate students, the same type of program could be developed for the GOR students. Larimer wrote the program which interfaced ten large programs which were already being used by the electrical engineering students. The TOTAL program is very successful and from conversations with the electrical engineering students it is used in both course work and in thesis work.

The GOR program could use a similar type of program. However, unlike the electrical engineering program, the operations research program does not have a current library of programs which the GOR students use on a regular basis. After such a library of programs is developed and the curriculum course work makes regular use of them, then an interactive program similar to TOTAL could be very useful.

VII. ALGORITHM SELECTION METHODOLOGY

Introduction

Problem formulation is considered a key issue in most textbooks and articles dealing with the operations research process. Albert Einstein is reported to have stated that the proper formulation of a problem was even more essential than its solution (Ref 41:25). In the textbook, Principles of Operations Research for Management, the authors state,

> The most critical concept in problem formulation is the process of explicitly and unambiguously stating the essentials of a problem: relevant variables and parameters, constraints or restrictions, and surrogate criteria or objective functions. The explicit statement of the problem represents our "blueprint" which guides us as we "build" our problem solution. Without the blueprint, the chances of achieving a match between problem solution and basic criteria are sharply reduced. (Ref 7:8)

Perhaps the process of problem formulation could be broken down into the following steps as illustrated by the flowchart in Figure 6. As the flowchart is examined, two infinite loops are observed. First the analyst may be overwhelmed in data and be unable to recognize that there is a problem. Second, after a problem is observed, the analyst may not be able to formulate the problem so that it can be solved. In other words, the problem as observed cannot be formulated as one of the problem types which this analyst is able to solve.

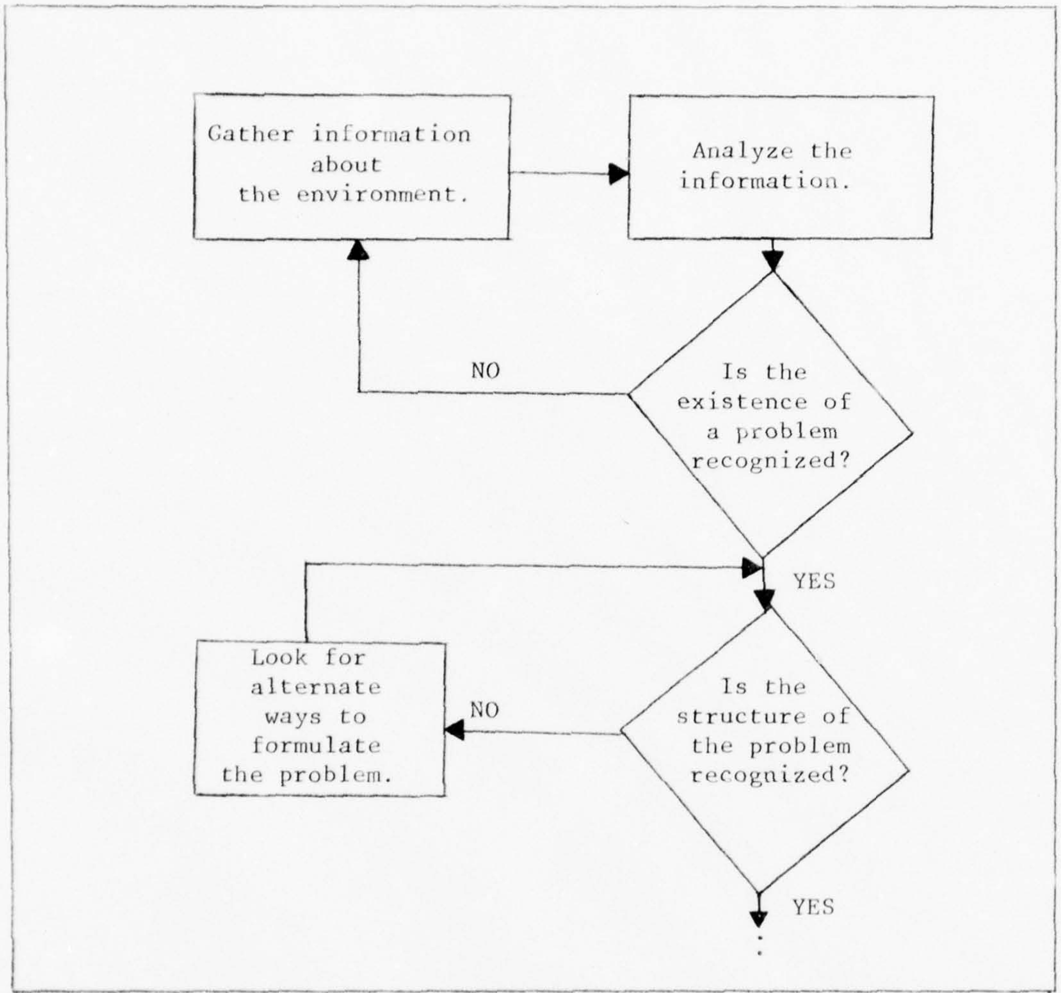

Figure 6. Flowchart of the Problem Formulation Step in the Operations Research Process.

In this chapter the second potential infinite loop will be examined more closely. First, a section on the background and importance of problem formulation. This will be followed by sections on some of the current methods of recognizing the correct problem type. Then there will be a section where some methods attempted during this thesis will be documented with problems which prevented development of a method to solve this problem. Last there will be a

short discussion of a potential method to approach this problem using an interactive computer program.

Background

The task of recognizing a solvable problem in the data provided to the analyst has been around for years. In chapter three the historical relationship between operations research and the computer was presented. If the time line in Appendix B is examined, possibly it could be concluded that problems were only solved when an individual could both recognize that there was a problem and correctly formulate it. Charles Babbage with his analysis of the British post office pricing policy is a good example of this. The post office had been losing money so the problem was obvious, yet it was Babbage's ability to formulate it that enabled a viable solution to be presented. The solution of pricing the delivery of mail by its size and weight and not by the delivery distance was implemented with profitable results (Ref 11).

Also the early work of the World War II operations research teams contains many illustrations of the study of data for a problem which was then formulated and solved. This ability is still needed by the present day operations research analyst. T. Bernard Tate in his 1977 article related that he has found operations research students having difficulty structuring problems into a recognizable formulation which could be solved (Ref 46:772). In the last chapter of Frederick S. Hillier and Gerald J. Lieberman's book, Operations Research, the importance of problem formulation is stressed. In fact key motivation

for correct problem formulation is contained in this sentence. "It is difficult to extract the 'right' answer from the 'wrong' problem!" (Ref 25:739)

This problem that analysts face was highlighted at a Panel Session of the Joint National Meeting of the Institute of Management Sciences and the Operations Research Society of America, November 17-19, 1975. David Kassing, President of the Center for Naval Analyses, stated in an abstract of his remarks the following:

> To be effective as a practicing management scientist, the analyst must work on the problem the policy-maker faces. This means that he must first identify the problem and then select the technique to use. Unfortunately, the emphasis on technique in today's OR curricula often leads the new practitioner to define the problem in terms of the techniques he has been taught. More often than not, none apply directly. It would be helpful, therefore, if students were assigned a variety of unstructured problems and left to their own devices in analyzing them." (Ref 40:112)

At that same Panel Session there were others who expressed the same concern about the ability to formulate correctly the problem given.

In Interfaces on February 1978, Robert J. Graham of La Salle College again expresses the need for good problem formulation. However, he suggests that the root of the problem is the lack of methods for problem identification (Ref 21:82). So this leads to the question, what work has been done on the development of methods of problem identification? This will be the subject of the next section.

Published Methods of Problem Identification

After a search of the literature, the methods of problem identification can be designated as either descriptive or prescriptive in

philosophy. The format of each method's presentation is usually in one of the following types.

1. Lists or catalogues of information
2. Tree structures of the information or of the decision process
3. Flowcharts usually of the decision process
4. Tables of information or decision choices

A brief discussion of each of the above formats will follow. During each discussion some of the actual occurrences in the literature of these formats will be referenced.

Lists and Catalogues. This is the most common method of presenting the different methods of problem solution. The lists or catalogues vary in size from just a part of a page to entire books devoted to lists of methods. In Dr. Billy E. Gillett's text, Introduction to Operations Research, three pages in the introduction is used for a typical version of the short list. He divides operations research problems into these eight major categories.

1. Sequencing
2. Allocation
3. Routing
4. Replacement
5. Inventory
6. Queueing
7. Competitive
8. Search (Ref 19:3)

Then Dr. Gillett provides a short description of each category. In this

text, as with most other textbooks using the list or catalogue format, the rest of the book is devoted to details on each of these subjects.

In the book, Principles of Operations Research for Management, (1977) operations research models are presented in an organization called by the authors "Taxonomy of OR Models". The following outline is adapted directly from the figure in that textbook.

OPERATIONS RESEARCH MODELS

I. Deterministic

  A. Nonlinear Optimization

    1. Classical Methods
    2. Search Methods
    3. Nonlinear Programming

  B. Linear Optimization

    1. Linear Programming
    2. Transportation
    3. Assignment
    4. Integer Programming
    5. 0-1 Programming
    6. Networks
    7. Goal Programming

II. Hybrid

    1. Dynamic Programming
    2. Inventory
    3. Simulation
    4. PERT-CPM
    5. Heuristics

III. Stochastic

1. Stochastic Programming
2. Queuing
3. Stochastic Processes
4. Decision Theory
5. Game Theory (Ref 7:18)

The authors then give a brief verbal description of the interrelationships among the different model types.

The most extensive catalog of operations research methods found during the literature search is Operations Research Handbook by Horst A. Eiselt and Helmut Von Frajer. The authors presume a certain level of mathematical expertise on the reader's part, and this appears to be a fine reference text. The authors present over one hundred different operations research algorithms covering the same categories as are found in the usual textbooks. Two items make this catalog of special interest. First each algorithm is presented in the following format as explained in the book's preface.

a) Hypotheses: Here the problem is formulated and the prerequisites are explained.

b) Principle: Briefly the general concept is presented.

c) Description: In this section each step of the algorithm or method is explained in a standard format.

d) Example: For each paragraph [Note: paragraph is the authors' word for algorithm] an example is completely solved. (Ref 13:5)

The examples make this list of methods most valuable. They are simple enough to go through with pencil and paper yet they illustrate

clearly the method under discussion. The second item which makes this reference book valuable is the extensive bibliography. It includes references which have not been translated into English.

All of the lists or catalogs which were found in the literature search were descriptive in nature. This may be due to the nature of a list or catalog since there is normally no provision for choices or selections based upon some criteria.

Tree Structures. This format of presenting information is usually used in a descriptive fashion in the literature to show the relationships between the different operations research methods or algorithms. The very simple ones are similar to the lists; just the format of presentation has been changed. An example of this is the classification of models given by Dr. Jay W. Forrester at the beginning of Chapter four of Industrial Dynamics (Ref 132:49). The most detailed descriptive tree found was in Thomas L. Saaty's article, "Operations Research: Some Contributions to Mathematics". This tree is up to eleven levels deep with one to five branches at each level. This tree structure is devoted to methods of optimization and is itself an excellent taxonomy of classical optimization.

Tree structures, like lists, provide few examples of prescriptive trees. A possible reason for this is that the tree structure can grow very large with just a few levels and choices at each level. This is reflected in the literature as the prescriptive trees are on a very specific topic. An example of a binary type tree is the decision process flowchart in the Vroom-Yetton model. While the authors call it a flowchart, it is a binary decision tree. This tree does not deal with

operations research material; however it shows clearly that ten levels of a binary tree--even when not a full tree--will fill an entire page with the presentation (Ref 30:426).

The most detailed prescriptive tree that dealt with an operations research related topic was the booklet, A Guide for Selecting Statistical Techniques for Analyzing Social Science Data. While this booklet was oriented to analytical tools available with a specific computer statistics package, the booklet has a good bibliography and the decision tree is very readable (Ref 4).

Flowcharts. Throughout the literature there are many small flowcharts illustrating different decision processes. However there are few that deal with broad areas of operations research. The largest flowchart found is in Robert E. Shannon's book, "Systems Simulation, the Art and Science. This flowchart is designed to help the user select the 'best' simulation programming language based upon the characteristics of the problem. The flowchart and associated discussion consist of twelve very useful pages (Ref 41:121). This flowchart uses the standard symbols for programmer's flowcharts. Because decisions are inherent to flowcharts, it was no surprise that all those found in the literature were prescriptive in nature.

Tables. Information becomes very compact when presented in a table. In spite of this seeming advantage, there are few examples of tables used in the literature to aid in the choice of a correct algorithm to solve an operations research problem. The best example found is in the opening pages of W. J. Conover's book, Practical Nonparametric

Statistics, 1971. This table deals with choosing the appropriate nonparametric test given the type of sample obtained and the type of hypothesis to be tested (Ref 9:xii). The rest of the textbook is devoted to detailed explanations of each of the items referenced in this table.

Thesis Attempted Algorithm Selection Methodology

After a survey of the literature, it becomes very clear that the number of different methods which have been used to solve operations research problems is very large. The following table is a list of the different types of operations research problems identified in some of the current literature. There are duplicates on the list as different authors make different divisions as to the types of problems. Also, no definition as to the meaning of each method will be given since authors sometimes differ in defining the problem types. This list may not be exhaustive, and it is possible to have missed some key technique or problem type used in operations research. The following table has 63 entries.

TABLE V

Types of Operations Research Problems

Allocation	Matching Problems
Assembly Line Balancing	Mixed/Integer Programming
Assignment	Networks
Bayesian Decision Models	Nonlinear Optimization
Big M Method	Nonlinear Programming
Binary Linear Programming	Parametric Linear Programming
Branch and Bound Method	PERT
Budget Problems	Plant Location Models
Classical Optimization	Portfolio Models
Competitive Model	Quadratic Programming
Convex Programming	Queuing
CPM	Random Numbers
Cutting Plane Method	Regression Analysis
Decision Theory/Analysis	Reliability
Deterministic Models	Replacement Models
Discrete Programming	Routing
Dynamic Programming	Scheduling
Fixed Charge Problems	Search (for information or decision)
Game Theory	Search Methods (nonlinear)
Geometric Programming	Sensitivity Analysis
Goal Programming	Separable Programming
Graph Theory	Sequencing
Heuristics	Set Covering
Hybrid (deterministic and stochastic)	Simulation
Implicit Enumeration	Stochastic Processes
Integer Programming	Stochastic Programming
Inventory	Transportation
Knapsack Problems	Transshipment
LaGrange Multipliers	Traveling Salesman
Linear Optimization	Utility Models/Theory
Linear Programming	Zero-One Programming
Markov Chains	

(Ref 1,7,12,13,19,34,37,47)

Since a prescriptive method to classify the different type of problems is the desired goal, a table of characteristics of operations research problems was generated. These characteristics were selected from those used in the literature.

TABLE VI

Characteristics of Operations Research Problems

Absorbing States	Nominal Data
Accessible States	Nonlinear Process
Additivity	Objective Function
Aperiodic States	Linear
Competition	Nonlinear
Conflict	Multiple
Constraints	One to One Assignment
Linear	Optimal Route
Nonlinear	Ordinal Data
Multiple	Policy Decisions
Controllable Variables	Proportionality
Deterministic Process	Random Process
Divisibility	Random Variables as Parameters
Duality	Recursive Relationships
Effectiveness to be Optimized	Risk
Equality Constraints	"Rules of Thumb"
Expected Cost	Sequence or Order Important
Finite Resources	Stages of System
Flow Information	States of System
Geometry	Stochastic Process
Inequality Constraints	Stock Levels
Infinite States	Time-Cost Tradeoffs
Integer Restriction	Uncertainty
Interval Data	Uncontrollable Variables
Iterative Solution	Waiting Lines
Linear Process	

This table is included to show the overlapping and generalized nature of problems made possible by these characteristics. Also the characteristics sometimes are so specific for a certain type of operations research problem that if the user understands the characteristic, then the user also probably knows if that is the technique to use. Conversely it cannot be assumed that the characteristics for unfamiliar problem types would be understood by the user.

Determining the format for displaying the information so that the user could choose the best algorithm for a specific problem became the next difficulty. In searching the literature for possible formats to display the information, the 1967 text by Carl E. Gregory was an excellent source. In a chapter on organizing data the following table was found.

TABLE VII

List of Alternate Ways of Organizing Data (Ref 23:99)

Abstracts	Flow charts
Algorithms	Graphs
Analogies	Guides
Bisociations	Handbooks
Blueprints	Illustrations
Books	Interfaced independent variables
Catalogues	Interpolations
Charts	Linear programs
Classifications:	Listings
Attributes:	Manikins
Energy	Manuals
Physical	Maps
Physiological	Mathematical models
Psychological	Matrix structures:
Sociological	Bisections
Cultural	Freezing
Economic	Fusions
	Juxtapositions

- Ethnic
- Functional
- Geographic
- Historical
- Levels
- Objectives
- Phases
- Political
- Rankings
- Spatial relations
- Time lines

Compilations
Condensations
Conjunctions of differences
Descriptions
Diagrams
Digital analogues
Drawings
Dynamic graphs
Enlargements
Facsimiles
Files:

- Alphabet
- Binary number systems
- Chronology
- Clipping
- Color
- Key punch
- Magnetic
- Memory bank
- Notching
- Number
- Size
- Subject
- Tapes

- Matrix algebra
- Overlays
- Synthesis
- Trisections

Milestones
Miniatures
Mock-ups
Models
Morphological formats
Multidimensional scaling
Multifactorial correlation
Nomographs
Outlines
Paradigms
Patterns
Photographs
Pictographs
Pictures
Q-sorts
Reports
Research models
Schedules
Schemata
Semantic differentials
Sequential programs
Simulations
Specifications
Statements
Syllabi systems
Tables
Trial balances
Varied 7 x 7 technique applications

When the large number of operations research methods and characteristics is considered, an immediate problem becomes evident. Any method of display which would be usable for the GOR student could be a very large document. The format which is easiest for the novice to use is the flowchart. This is because the decisions are faced one at a time and the final square of the flowchart is the needed answer. For a flowchart to be useful the detail needs to be similar to the simulation

language selection flowchart in Shannon's book. If the number of operations research problem types could be reduced to 25 and the number of characteristics limited to 25, then such a flowchart would would still be very large. If the order of the characteristics is not important, then the number of decision points in the flowchart is 2^{25}; and if the order of the characteristics is important, then the upper limit on the number of decision points is 25 factorial. Either document is going to be too large for practical use.

The other problem which makes an absolute set of rules for choosing an appropriate algorithm difficult is the many variations to each of the previously given problem types. For example in linear programming it is possible to approximate nonlinear objective or constraint functions. Many of the other methods allow special modifications to each of them for the solving of special classes of problems.

Finally it becomes obvious that for any selection method to be useful, more than just the name of the solution technique or problem type is needed. The document containing the selection methods either needs extensive explanation of each method or a very thorough bibliography of information on each of the problem types and their solution. Since the number of methods is so large and amount of information needed is great, a possible method of implementing an algorithm selection methodology would be to use the computer in an interactive mode to aid in the decision process. This will be discussed in the next section.

Automated Algorithm Selection Methodology

The use of the computer to assist in the management of information

is not a new concept; however the following possible interactive computer program would be new. Two other existing programs prompted the consideration of automated algorithm selection. The first program is TOTAL. TOTAL was the interactive computer program done as a thesis effort by Larimer at AFIT in 1978. This program is heavily used by the electrical engineering department for the formulation and solution of numerous problems. However the user must already know what the problem type is to be able to use TOTAL. The second program is an interactive game called ANIMAL (Ref 10). This game written at Dartmouth College allowed either the computer to guess the animal that the player was thinking of or for the player to guess the animal that the computer had selected. The program was able to learn new animals and the characteristics which distinguish them from the previously known animals.

With both of those programs and with the potential size of the data base in mind, the structure in Figure 7 is proposed.

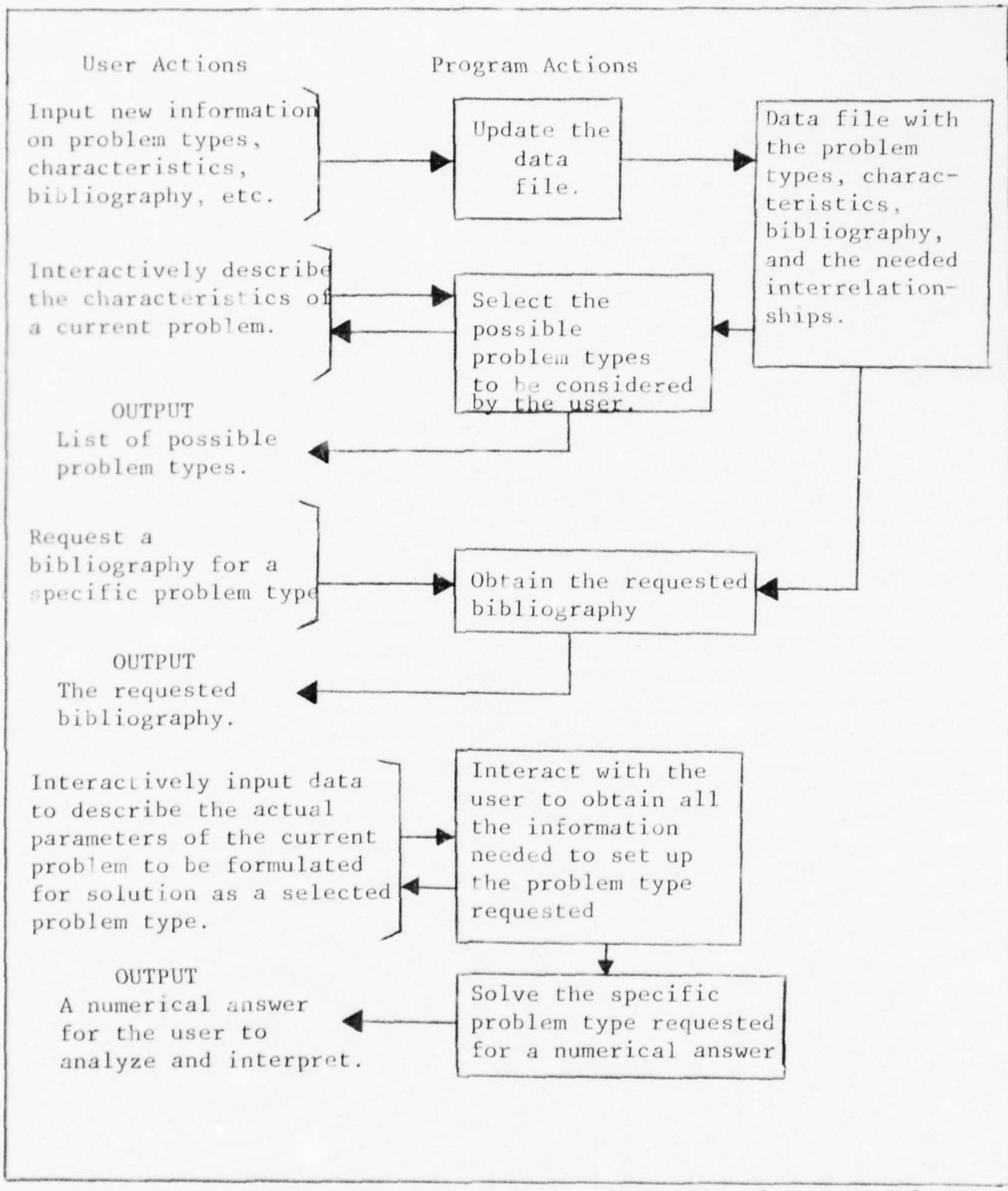

Figure 7. Flow Diagram for Automated Algorithm Selection Methodology

The proposed program could be useful for both students and researchers. If the data base was kept up to date on the current literature in the field of operations research relating to each of the problem types, then this alone could be very useful.

This automated algorithm is in two distinct parts as shown by the flow diagram. In the first part only the selection of the appropriate problem type, when given the characteristics of a current problem, is being implemented. The ability to update the data base is needed as the field of operations research will continue to grow. The information stored in the data base could be modified to include information on what problem types can currently be solved with the available computer resources. This data base may be a problem since the bibliography could be very large. However, for an implementation of this program to assist graduate operations research education, the only references necessary are those actually available at the school.

Both parts of the automated algorithm are needed for it to be useful; since, if all the program can do is guess at the problem type then the user is provided only the possible problem type and maybe some bibliography references. The second part of the program will allow the user to input his numerical data which describes the problem and to analyze the results to see if they are meaningful. This could be very useful in a graduate operations research program to train students in recognizing problem types when given a description of a situation. Since the computer is used for the dirty work of getting actual numerical answers, there may be more time available to expand the types of problems attempted during a course.

Potential Problems. There are at least three problems in the actual development of this program. First the physical size of the data base may be a problem. While the problem types and characteristics will not require much storage space, the bibliography may require a great deal of storage space if a complete bibliography is maintained. Second, actually describing the different problem types so that they can be individually differentiated may be the most difficult part of the project. This is where the use of a program which can 'learn' the proper set of characteristics which describe each of the different problem types might be very useful. The problem of describing the distinct set of characteristics which delineate a specific problem type is complicated by the use of a variety of different and similar terms by the authors in the literature. The program could be less useful for those users who learned a different set of operations research terms and definitions. Third, there does not exist a set of user oriented application programs for the operations research type of problems which are in current and active use at AFIT. This was discussed in Chapter VI.

VIII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

There were three major efforts in this thesis. These results were the development of a historical relationship between operations research and the computer, the development of a model describing the computer support for graduate operations research education, and the development of a proposed method of selecting the "best" algorithm.

The historical relationship between operations research and the computer was developed using a search of the literature. The historical information was collected and compiled into a time line and bibliography which is in Appendix B. The time line was analyzed to determine the relationship between these fields. Since developments in either field have enhanced the abilities of the other field, this relationship may be characterized as synergistic.

The model of computer support for graduate operations research education used a literature search to collect current information on educational models. The model of computer support for graduate operations research education was defined and a checklist developed to assist in the evaluation of an actual graduate operations research program. Finally, the Air Force Institute of Technology's Graduate Operations Research Program was evaluated using the checklist.

The method of selecting the "best" algorithm began with a literature survey of current developments in the field. After examining the difficulties of a manual method, a proposal for an automated method for algorithm selection was developed.

Also, during the thesis effort there were several other items attempted. The guide to using LPKODE, A linear programming program, was written and is in Appendix E. The User's Guide to AFIT GOR's Computer Support was written and is in Appendix C. Finally during the literature search, algorithms which could apply to operations research were compiled, and a copy of this is in Appendix D.

Conclusions

The three major conclusions of this research effort are as follows:

1. There is a historical relationship between operations research and the computer. And an understanding of this relationship will help the operations research analyst in approaching contemporary problems.
2. The model of computer support for graduate operations research education could be useful for managers in either operations research education or in computer support of education.
3. The problem of selecting the "best" algorithm is very complex and may require the use of a computer to handle the data and search for the "best" algorithm.

Recommendations

Most of these recommendations could be potential thesis topics. Some of these recommendations were planned as a part of this research, but most derived from areas of this thesis which needed more research. Unfortunately time is not an unlimited resource; so, hopefully someone else might find these recommendations useful.

1. Conduct and analyze a survey of operations research analysts

in the United States Air Force to determine the types of problems actually being faced and the degree of reliance on computer support. A related survey to this would be to attempt to determine what the analysts' supervisors wanted the analysts working for them to be able to do. The results from these surveys could have a strong impact upon the curriculum of graduate operations research programs in many schools including AFIT.

2. Conduct a search of the literature for potential case studies which could be used in the graduate operations research program. Since there are several texts of industrial case studies, this would be more useful if limited to the military uses of operations research. From the records of World War II there may be several very valuable case studies. Potential problems here could include classified data and missing data due to the deaths of key individuals.

3. Conduct a search of the literature case studies in the ethics of analysis. This could be narrowed to a historical study of how the military operations research analyst's work is used by the different facets of the military and civilian community.

4. Implement the program discussed in Chapter VII. This could be done at different levels of sophistication depending upon the desired end result. This would require a large amount of application software to be written to solve the different problem types.

5. Conduct a cost effectiveness study on the feasibility of the Aeronautical Systems Division purchasing APEX III for the CYBER 74 computer system. APEX III is the Control Data Corporation's program for the solution of linear programming problems. It can solve

integer and mixed/integer programming problems. It is able to solve large linear programming problems of approximately 9,000 variables.

6. Develop a series of programmable calculator programs to support the graduate operations research program at AFIT.

7. Develop a measurement device based upon the model in Chapter IV of computer support for graduate operations research education. It could include both surveys, interviews, and quantitative measures. This could be applied to several graduate operations research programs in an attempt to verify the model.

8. Develop a measurement device based upon the Graduate Operations Research Education model of Chapter IV, Figure 5. Probably to get enough data all of the graduate education program would have to be used as a sample. This research could quantify the internal relationships in the graduate education environments and perhaps be related to the various organizational climate studies.

9. Develop a library of applications programs which solve many operations research techniques. This could be done as course work or as a series of different theses depending upon the difficulty of the techniques implemented.

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APPENDIX A

INTERVIEW QUESTIONS AND ASSOCIATED COVER LETTER

For this interview a very broad definition of operations research will be used. Operations research includes for this interview at least the following: economics, econometrics, statistics, simulation, and classical mathematical approaches.

1. What Operations Research curriculum courses have you taught?

2. What AFIT computer resources did these courses require the graduate operations research student to use?

3. What computer resources if available would enhance the learning in these courses? (algorithms, programs, subroutines, types of problems which could be solved by the computer)

4. What AFIT computer resources have you used for personal research here at AFIT?

5. Do you have any algorithms or programs which the operations research curriculum could use if generally available?

6. When you consider the currently available AFIT computer resources which support operations research, which routines, programs, software, hardware, etc., do you consider the most valuable? Please list your first through fifth choice.

    1.

    2.

    3.

    4.

    5.

7. If only three additional algorithms could be added to the AFIT computer resources supporting operations research, then what three would you choose in order of preference?

    1.

    2.

    3.

DEPARTMENT OF THE AIR FORCE
Air Force Institute of Technology (AU)
Wright-Patterson Air Force Base, Ohio 45433

REPLY TO
ATTN OF: ENA/Capt Robert M. Schumacher/GOR-78D (Box 4285)

SUBJECT: Interview Questions

TO:

1. The purpose of this letter is to transmit the questions for the scheduled interview. The results of the interview will be used to complete thesis requirements of the Graduate Operations Research Program.

2. The interview questions are attached so that you can preview them before the interview. The interview results will be summarized and only on questions number five would you be personally identified. Thank you for your assistance.

ROBERT M. SCHUMACHER
Captain, USAF
GOR-78D

APPENDIX B

OPERATIONS RESEARCH AND COMPUTER TIMELINE AND BIBLIOGRAPHY

The timeline is followed by the bibliography. The entries in the timeline were selected because they were felt to have a key role in the development of both fields. Each timeline entry has one or more reference numbers which are indexed to the bibliography so that the reader could examine the sources used for this timeline. A few of the timeline entries reference a zero bibliography entry. This entry does not exist in the bibliography since they are references to The Bible. These few timeline entries contain the exact reference at the end of the specific entry.

The timeline and the bibliography were generated using the CYBER 74 computer system with some simple FORTRAN programs. Since there is no ability to underline, the convention adopted was to put two slashes at the start of underlining and then two more slashes at the end of underlining.

Example:

The Bible would be in the bibliography as //THE BIBLE//.

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SURVEY AND EXTENSION OF AFIT COMPUTER RESOURCES TO SUPPORT GRAD--ETC(U)
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OPERATIONS RESEARCH	DATE	COMPUTERS
MESOPOTAMIA REF:33 USE OF CLAY TABLETS FOR PERMANENT RECORDS.	5000 B.C.	
EGYPT REF:16 PROBABLE INTRODUCTION OF EGYPTIAN CALENDAR.	4228 B.C.	
	3800 B.C.	BABYLON REF: 4 SURVEYING AND MAPMAKING IN BABYLONIA.
	3000 B.C.	ORIENT REF: 4 DEVELOPMENT OF THE ABACUS AND SOROBAN.
IRAQ REF:17 A PRE-CHESS GAME WITH MILITARY PIECES PLAYED AS A WAR GAME. IT IS SIMILAR TO THE HINDU GAME OF THE SAME TIME KNOWN AS 'CHATURANGA'.	3000 B.C.	
EGYPT REF:16 GREAT PYRAMID OF GIZEH ERECTED, 19 ACRES AT THE BASE.	2900 B.C.	
BABYLON REF:43 HAD A SCHOOL OF COMMERCIAL ARITHMETIC FOR TRADERS. NOTE: THE MATH WAS BASE 60.	2250 B.C.	
NIPPUR REF:16 DATE OF MANY MATHEMATICAL TABLETS FOUND AT NIPPUR; MYTHICAL DATE OF THE LO-SHU, THE OLDEST KNOWN EXAMPLE OF A MAGIC SQUARE.	2200 B.C.	
MOSES REF: 0 JETHRO, MOSES' FATHER IN LAW, AFTER STUDYING THE CURRENT MANAGEMENT PRACTICES ADVISES MOSES TO USE A CHAIN OF COMMAND WITH MANAGEMENT BY EXCEPTION AS THE LEADER OF ISRAEL. EXODUS 18:13-27.	1491 B.C.	
CHINA REF:16 POSSIBLE DATE OF THE CHOU-PEI, OLDEST CHINESE MATHEMATICAL WORK.	1105 B.C.	
THALES REF:16 BEGINNING OF DEMONSTRATIVE GEOMETRY.	600 B.C.	
PYTHAGORAS REF:16 WORKED ON GEOMETRY AND ARITHMETIC.	540 B.C.	
NEHEMIAH REF: 0 PRESENTS TO KING ARTAXERXES OF PERSIA THE COMPLETE PLAN FOR REBUILDING THE CITY OF JERUSALEM INCLUDING THE COSTS AND TIME REQUIRED TO DO IT. HE WAS SENT TO SUPERVISE THE REBUILDING OF JERUSALEM. NEHEMIAH 2:5-8.	446 B.C.	

OPERATIONS RESEARCH	DATE	COMPUTERS
	400 B.C.	SALAMIS REF:25 A MARBLE COUNTING TABLE OF ABOUT THIS DATE WAS FOUND. IT IS MARKED IN A DECIMAL SYSTEM.
THYMARIDAS REF:16 SOLUTIONS TO SYSTEMS OF SIMPLE EQUATIONS.	350 B.C.	
ARISTOTLE REF:16 SYSTEMATIZER OF DEDUCTIVE LOGIC.	340 B.C.	
PLATO REF:16 EMPHASIZED MATHEMATICS IN THE TRAINING OF THE MIND.	340 B.C.	
EUCLID REF:16 WORKED IN NUMBER THEORY, AND WROTE //ELEMENTS//.	300 B.C.	
ARCHIMEDES REF:16 GREATEST MATHEMATICIAN OF ANTIQUITY, WORKED WITH: CIRCLE AND SPHERE, COMPUTATION OF PI, INFINITE SERIES, METHOD OF EQUILIBRIUM, ETC.	225 B.C.	
ARCHIMEDES REF:20,41 AT SYRACUSE, DEVISED A MEANS TO BREAK THE NAVAL SEIGE.	215 B.C.	
	100 B.C.	GREECE REF: 4 A GREEK ANALOG COMPUTER FOUND IN 1901 IN A SHIPWRECK.
JESUS CHRIST REF: 0 JESUS CHRIST TELLS THE MULTITUDES WHO FOLLOWED HIM TO COUNT THE COST OF DISCIPLESHIP. THEN HE ILLUSTRATED WITH DOING A COST ANALYSIS BEFORE BUILDING A TOWER OR TO DO A MANPOWER ANALYSIS BEFORE GOING TO WAR. LUKE 14:25-33.	30	
ROMAN EMPIRE REF:33 MORTALITY TABLES FOR ROMAN INSURANCE COMPANIES CALCULATED BY HAND.	346	
EGYPT REF:16 LAST LIBRARY AT ALEXANDRIA BURNED.	641	
	960	GERBERT AURILLAC REF:23 GERBERT AURILLAC (POPE SYLVESTER II) INVENTS A VARIATION TO THE ABACUS.
	960	MAGNUS REF:23 A SPANIARD NAMED MAGNUS INVENTS A CALCULATOR REPORTEDLY MADE IN BRASS AND SHAPED LIKE A SKULL. DESTROYED AFTER HIS DEATH
ITALY REF:33 DOUBLE ENTRY BOOKKEEPING PERFORMED IN ITALY.	1340	
TRAVISO REF:32 WROTE A BOOK ON ARITHMETIC FOR BUSINESS IN THE 15TH CENTURY.	1400	

OPERATIONS RESEARCH	DATE	COMPUTERS
	1449	JAMSHID AL KASHI REF:21 HE HAS THE FIRST USE OF DECIMALS, CALCULATED PI TO 16 PLACE DEVELOPED TRIGONOMETRY, BUILT A MECHANICAL LUNAR CONJUNCTION COMPUTER, AND A MECHANICAL PLANETARY LOCATION COMPUTER. HIS WORKS WERE LOST AFTER HIS DEATH AND THIS INFORMATION WAS FOUND ONLY AFTER THE ITEMS WERE REDISCOVERED.
PACIOLI REF:16,32 WROTE, //SUMMA DE ARITHMETICA//, WHICH WAS THE FIRST DESCRIPTION OF DOUBLE ENTRY BOOK-KEEPING AS DONE IN VENICE. HE ALSO WORKED WITH ALGEBRA AND ARITHMETIC.	1494	
	1500	LEONARDO DA VINCI REF:23 SKETCHES A CALCULATOR TO ADD AND SUBTRACT WITH A CARRY. AS USUAL THIS WAS IN CODE AND ONLY WAS DISCOVERED THIS CENTURY.
NICCOLO MACHIAVELLI REF:41 MACHIAVELLI OF THE FLORENTINE REPUBLIC HAS HIS ARTICLE, 'WHAT DANGERS ARE RUN BY ONE WHO TAKES THE LEAD IN ADVISING SOME COURSE OF ACTION', PUBLISHED POSTHUMOUSLY IN ROME.	1531	
HUGH OLDCASTLE REF:32 FIRST DESCRIBED THE ENGLISH METHOD OF BOOK-KEEPING.	1543	
	1580	FRANCOIS VIETA REF:21 FIRST USED LETTERS FOR UNKNOWNS. THE FOUNDER OF MODERN ALGEBRA.
WILLIAM SCOTT (ENGLAND) REF:32 WROTE, //ESSAY ON DRAPERY//, A BOOK ON TRADING IN THE 17TH CENTURY.	1600	
JACQUES SAVOY OF FRANCE REF:32 WRITES ON MATH AND BUSINESS IN THE 17TH CENTURY.	1600	
JAN IMPYN REF:32 WROTE THE FIRST DUTCH BOOK ON ACCOUNTING IN THE 17TH CENTURY	1600	
	1614	JOHN NAPIER REF: 4 DEVELOPS LOGARITHMS.
	1617	JOHN NAPIER REF: 4 MAKES NAPIER'S BONES AS AN AID TO MULTIPLICATION.
	1617	JOHN NAPIER REF:21 WROTE //RABDOLOGIA// WHERE THE USE OF THE DECIMAL POINT IS FIRST EXPLAINED.
	1620	EDMUND GUNTER REF:21 DEVELOPS AN EARLY PRE 'SLIDERULE'.
	1623	WILHELM SCHICKARD REF:21 BUILT A MACHINE TO DO ALL FOUR ARITHMETIC FUNCTIONS. THIS INVENTION WAS LOST TO A FIRE DURING THE PLAGUES.
	1624	WILHELM SCHICKARD REF:37 BUILT A CALCULATING CLOCK WHICH COULD ADD, SUBTRACT, AND TELL TIME.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1630	RICHARD DELAMAIN REF:21,30 INVENTS A SLIDERULE.
	1632	WILLIAM OUGHTRED REF: 4,21 MAKES THE FIRST SLIDERULE.
FERMAT REF:16 WORKED ON NUMBER THEORY, MINIMA AND MAXIMA, PROBABILITY, AND ANALYTIC GEOMETRY.	1635	
	1637	RENE' DESCARTES REF:21,27 DEVELOPED USE OF GRAPHS FOR FUNCTIONAL RELATIONSHIPS. AN EARLY ANALOG.
	1642	BLAISE PASCAL REF: 4,29,30,46 INVENTS FIPST ADDING MACHINE, A DIGITAL MECHANICAL CALCULATOR.
	1642	BLAISE PASCAL REF:13,21 INVENTS THE FIRST MATHEMATICAL DIGITAL CALCULATOR.
CHRISTOPHER WEIKHMANN REF:17 INVENTED 'KINGS GAME' TO TRAIN ROYALTY IN THE ART OF WAR. IT IS ACTUALLY ANOTHER MODIFICATION OF CHESS.	1644	
	1645	BLAISE PASCAL REF:37 BUILT A CALCULATOR TO ADD AND SUBTRACT. IT WAS GIVEN TO JOHANNES KEPLER WHO DEVELOPED IT FURTHER.
	1647	BLAISE PASCAL REF:44 SHOWED DESCARTES THE ARITHOMETER.
	1649	BLAISE PASCAL REF:44 SHOWED THE ARITHOMETER TO CHANCELLOR SEGUIAR FOR PRIVILEGE ROYAL.
	1663	SIR SAMUEL MORELAND REF:23 BUILT A TRIGONOMETRICAL CALCULATING MACHINE.
	1666	SIR SAMUAL MORELAND REF:44 BUILT AN ARITHOMETER LIKE PASCAL'S.
	1666	SIR SAMUEL MORELAND REF:40 BUILT THE FIRST OPERABLE MULTIPLIER.
	1666	SIR SAMUEL MORELAND REF:23 INVENTED A CALCULATOR TO ADD AND SUBTRACT.
	1671	GOTTFRIED WILHELM LEIBNIZ REF: 4 WROTE ABOUT A POSSIBLE MULTIPLICATION MACHINE.
	1671	GOTTFRIED WILHELM LEIBNIZ REF:23 INVENTED A CALCULATOR FOR ADDITION AND SUBTRACTION.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1678	LEIBNITZ REF:44 BUILT A CALCULATOR LIKE PASCAL'S.
	1678	GRILLET DE ROVER REF:44 BUILT A PASCAL-LIKE CALCULATOR.
	1678	GRILLET DE ROVER REF:23 BUILDS A CALCULATOR WITH A CARRY.
	1679	GOTTFREID WILHELM LEIBNIZ REF:37 SPECULATED ON A BINARY CALCULATOR.
SIR ISSAC NEWTON REF:16 NUMERICAL SOLUTIONS OF EQUATIONS.	1680	
GOTTFRIED WILHELM LEIBNIZ REF:15 DEVELOPMENT OF CALCULUS.	1682	
GOTTFREID WILHELM LEIBNIZ REF:39 DISCOVERED DETERMINANTS AND THEN IGNORED THEM.	1693	
SIR ISSAC NEWTON REF:47 SUGGESTED SENDING ABLE MATHEMATICIANS TO SEA TO IMPROVE NAVIGATION, IE. ANALYSTS AT THE OPERATIONAL LEVEL.	1694	
	1694	GOTTFRIED WILHELM LEIBNIZ REF: 4,13,21,37 INVENTS A STEPPED-WHEEL CALCULATOR THAT PERFORMS ALL FOUR ARITHMETIC FUNCTIONS.
MARQUIS DE VAUBON REF:47 LOUIS XIV'S MARSHAL OF FRANCE, APPLIED THE SCIENTIFIC METHOD TO OPERATIONAL SITUATIONS AND IMPROVED THE USE OF EXISTING WEAPONS.	1700	
SIR FRANCIS GALTON REF:39 COINED THE TERM 'REGRESSION LINE'.	1700	
	1709	GIOVANNI POLENI REF: 7,23 INVENTED A MECHANICALLY PROGRAMMED CALCULATOR.
THOMAS WATT REF:32 WROTE, 'AN ESSAY ON THE PROPER METHOD OF FORMING THE MAN OF BUSINESS'. THIS ESSAY EMPHASISED THE IMPORTANCE OF MATH.	1716	
	1725	BOUCHON REF:33 USED PERFORATED PAPER TAPE TO CONTROL A LOOM.
GABRIEL CRAMER REF:39 USED DETERMINANTS FOR THE RULE NOW KNOWN AS 'CRAMER'S RULE'.	1740	
QUESNAY REF:39 THE FRENCH PHYSICIAN AND ECONOMIST WROTE, 'TABLEAU ECONOMIQUE', AN ADVANCED AND THROUGH ANALYSIS SHOWING THE EXISTANCE OF 'GENERAL EQUILIBRIUM' IN THE ECONOMY.	1758	

OPERATIONS RESEARCH	DATE	COMPUTERS
QUESNAY REF:49 DEVELOPS MATH PROGRAM MODEL.	1759	
THOMAS BAYES REF:33 WROTE AN ARTICLE ABOUT THE THEORY WITH HIS NAME.	1763	
	1775	CHARLES, EARL OF STANHOPE REF:23 BUILDS A MACHINE WHICH WILL MULTIPLY.
ADAM SMITH REF:33,39 PUBLISHED, //INQUIRY INTO THE NATURE AND CAUSE OF THE WEALTH OF NATIONS//. USED THE SCIENTIFIC METHOD IN HIS ANALYSIS.	1776	
	1777	CHARLES, EARL OF STANHOPE REF:23 BUILDS A MACHINE WHICH ADDS.
	1779	CHARLES, EARL OF STANHOPE REF:21 CHARLES, EARL OF STANHOPE BUILDS A DESK CALCULATOR.
HELWIG, MASTER OF PAGES REF:17 HELWIG AT THE COURT OF THE DUKE OF BRUNSWICKS INVENTED A A GAME WITH 1666 SQUARES IN COLORS FOR TERRAIN. THE PLAY WAS LIKE CHESS FOR THE PIECES.	1780	
LAGRANGE REF:16 WORKED ON CALCULUS OF VARIATIONS, DIFFERENTIAL EQUATIONS, AND NUMERICAL SOLUTION OF EQUATIONS.	1780	
	1786	J.H. MULLER REF: 7 HAS AN IDEA FOR A DIFFERENCE MACHINE.
	1788	JAMES WATT REF: 4 DEVELOPS THE FLYBALL GOVERNOR.
	1790	CHARLES STANHOPE REF:23 BUILDS A MACHINE TO DO INDUCTIVE LOGIC.
	1791	MARGETTS REF:27 DEVELOPS TABLE TO DISPLAY RELATIONSHIPS OF THREE VARIABLES.
	1791	D'OCOGNE REF:27 DEVELOPS AN EARLY NOMOGRAM.
GEORGE VINTURINUS REF:17 WROTE 'RULES OF A NEW WAR GAME FOR THE USE OF MILITARY SCHOOLS'. IT HAD MANY 'REAL WORLD' RESTRICTIONS AND PROVISIONS OF MOVEMENT AND TERRAIN.	1797	
MARKOV (1856-1922) REF:49 DEVELOPS DYNAMIC MODELS. HIS WORK IS LATER KNOWN AS MARKOV CHAINS.	1800	
ENGLAND REF:33 FIRST OFFICIAL CENSUS DONE IN ENGLAND.	1801	

OPERATIONS RESEARCH	DATE	COMPUTERS
	1804	JOSEPH MARIE JACQUARD REF: 4,13,21 PERFECTS THE FIRST PUNCHED CARD MACHINE; USED TO WEAVE INTRICATE DESIGNES INTO CLOTH.
ADRIAN MARIE LEGENDRE REF:16 METHOD OF LEAST SQUARES FOR LINEAR TRENDS.	1805	
ADRIAN MARIE LEGENDRE REF:39 INTRODUCED LEAST SQUARES METHOD TO STUDY CURVILINEAR AS WELL AS LINEAR TRENDS.	1809	
VON REISSWITZ REF:17 DEVELOPED THE FIRST NON-CHESSBOARD TYPE WAR GAME. IT HAD TERRAIN MODELLED IN SAND.	1811	
	1812	CHARLES P. BABBAGE REF: 4,12,13 A PROFESSOR OF MATHEMATICS AT TRINITY COLLEGE, CAMBRIDGE, ENGLAND, THOUGHT OF BUILDING A DIFFERENCE ENGINE, CAPABLE OF AUTOMATICALLY COMPUTING TABLES.
	1814	J.M. HERMANN REF:40,70,21,25,27 DEVELOPS THE ROTATION PLANIMETER FOR MECHANICAL INTEGRATION.
	1819	CHARLES P. BABBAGE REF:12 STARTED SKETCHING THE DIFFERENCE ENGINE.
CARL FRIEDRICH GAUSS REF:21,39 DEVELOPS LEAST SQUARES, GAUSSIAN ELIMINATION, NUMERICAL INTEGRATION. HE GAVE THE NAME 'DETERMINATE' TO THE MATRIX RESULT.	1820	
CHARLES P. BABBAGE REF:12,37 DOES ANALYTICAL INVESTIGATION OF PIN-MAKING INDUSTRY AND THE PENNY-POST SYSTEM IN THE FORMAT OF AN OPERATIONS RESEARCH OR SYSTEMS ANALYSIS EFFORT.	1820	
	1820	CHARLES XAVIER THOMAS REF: 7,23,44 THOMAS OF COLMAR, ALSACE LORRAINE BUILT A CALCULATOR WITH INTERCHANGABLE PARTS FOR EASE OF PRODUCTION AND REPAIR. IT WAS A LEIBNIZ TYPE MACHINE AND BECAME THE FIRST COMMERCIAL CALCULATOR.
JAMES BENETT REF:32 WROTE, 'THE AMERICAN SYSTEM OF PRACTICAL BOOKKEEPING'.	1824	
	1824	GONELLA OF FLORENCE REF: 7 DEVELOPS A ROTATION PLANIMETER.
VON REISSWITZ'S SON REF:17 PUTS HIS FATHERS GAME ON ACTUAL MAPS AND BEGINS THE TRUE MODERN WAR GAME.	1824	
	1827	JOHANNES OPIKOFFER REF: 7 DEVELOPS A ROTATION PLANIMETER IN GERMANY.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1829	W.T. ODHNER REF: 7 BUILT A PINWHEEL AND CAM DISC CALCULATOR.
CAUCHY REF:16 RIGORIZATION OF ANALYSIS.	1830	
CHARLES P. BABBAGE REF: 6,37 HIS BOOK, //ON THE ECONOMY OF MACHINERY AND MANUFACTURES// ANALYZED THE PIN MAKING INDUSTRY WITH 'BEST KNOWN' METHODS.	1832	
	1834	CHARLES P. BABBAGE REF: 4, 7,12,13 DESIGNED AND PARTIALLY BUILT THE 'ANALYTICAL ENGINE', THE FIRST GENERAL PURPOSE DIGITAL COMPUTER.
KARL B. JACOBI REF:39 PUBLISHED //DE FORMATIONE PROPRIETATIBUS DETERMINANTIUM//.	1841	
	1843	SAMUEL F. B. MORSE REF:25 DESIGNED A 'READ ONLY MEMORY' USING MAGNETIC STRIPS FOR ASSISTING TELEPGRAPHIC TRANMISSIONS.
	1848	GEORGE BOOLE REF:21 PROPOSES FORMAL LOGIC AND BINARY LOGIC.
	1849	WETLI OF VIENNA REF: 7 IMPROVED PETER ANDREAS HANSON'S (GOTHA) ROTATION PLANIMETER.
	1850	D.D.PARMELEE REF:33,40 PATENTED THE KEY DRIVEN ADDING MACHINE.
	1851	EDWARD SANG OF EDINBURGH REF: 7 MR. SANG WITH CLERK MAXWELL, J. THOMSON, AND LORD KELVIN DEVELOP A PLANIMETER.
	1854	JAMES THOMSON REF:27 DEVELOPS A BALL AND DISK INTEGRATOR.
	1854	JAKOB AMSLER REF: 7,27 DEVELOPS THE POLAR PLANIMETER.
EDWIN T. FREEDLEY REF:33 WROTE,//A PRACTICAL TREATISE ON BUSINESS// A BOOK WHICH DEALS IN TOTAL COST OF AN ITEM TO FIGURE THE 'BEST' DEAL	1854	
	1855	JAMES CLERK MAXWELL REF:21 WORKS ON THE PLANIMETER.
	1859	CHARLES P. BABBAGE REF:33 A LARGE VERSION OF BABBAGE'S DIFFERENCE MACHINE WAS COMPLETED.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1863	CHARLES P. BABBAGE REF:33 BABBAGE'S DIFFERENCE MACHINE (1859) WAS USED TO CALCULATE LIFE TABLES FOR RATING INSURANCE.
ROBERT E. LEE REF:33 GENERAL LEE PROPOSED A COLLEGIATE SCHOOL OF BUSINESS TO THE INSTITUTION LATER KNOWN AS WASHINGTON AND LEE UNIVERSITY (NOT ACCEPTED).	1869	
	1871	CHARLES P. BABBAGE REF:13 DIES BEFORE THE ANALYTICAL ENGINE IS COMPLETED.
	1872	E.D. BARBOUR REF:33 PUT THE FIRST PRINTING DEVICE WITH AN ADDING MACHINE.
JORDON REF:49 DEVELOPS LINEAR MODELS.	1873	
LEON WALRAS REF:49 DEVELOPS MATH PROGRAM MODEL FOR ECONOMICS.	1874	
LEON WALRAS REF:39 USED MATHEMATICAL SYMBOLISM IN //ELE'MENTS DE ECONOMIE POLITIQUE//.	1874	
	1875	FRANK STEPHAN AND W.T. ODHNER REF:33 PRODUCED A MORE COMPACT CALCULATOR.
	1876	LORD KELVIN REF:21,27 BUILDS A HARMONIC ANALYZER TO GENERATE TIDE HEIGHT TABLES.
	1878	ABDANK ABAKANOWICZ REF: 7,27 BUILT AN INTEGRAPH WHICH DRAWS THE INTEGRAL CURVE WHEN PASSED AROUND THE PERIMETER OF FIGURE WHOSE AREA IS REQUIRED.
FREDERICK W. TAYLOR REF:20 USED SCIENTIFIC ANALYSIS TO INCREASE PRODUCTION.	1880	
	1881	ALLAN MARQUAND REF:23 INVENTS A MACHINE FOR PROPOSITIONAL LOGIC.
UNITED STATES REF:32 THE FIRST UNIVERSITY LEVEL BUSINESS SCHOOL IS FOUNDED AT WHARTON COLLEGE.	1881	
	1882	C.V. BOYS REF:27 DEVELOPS AN INTEGRAPH TO INTEGRATE FROM TWO DIMENSIONAL PLOT
	1885	DORR E. FELT REF:40 BUILT A CALCULATOR THAT COULD DO ALL FOUR FUNCTIONS PLUS CUBE AND SQUARE.
	1886	CHARLES L. DODGSON REF:23 MR. DODGSON (PENNAME--LEWIS CARROL) BUILT A LOGICAL ABACUS.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1887	LEON BOLLEE' REF: 7 BUILT A DIRECT MULTIPLYING MACHINE WHICH USED TABLES.
	1887	DORR E. FELT REF: 7 MR. FELT OF CHICAGO BUILT A CALCULATOR IN AMERICA.
AMERICAN STATISTICAL ASSOC. REF:33 "PUBLICATION OF THE AMERICAN STATISTICAL ASSOCIATION" IS FOUNDED.	1888	
	1888	WILLIAM S. BURROUGHS REF:40 BUILT A RECORDING TYPE CALCULATOR WITH DASHPOTS.
	1889	DR. HERMAN HOLLERITH REF: 4,21 DEVELOPED PUNCHED CARD MACHINES FOR THE 1890 UNITED STATES CENSUS.
	1890	DR. HOLLERITH REF:13 THE 1890 CENSUS WAS COMPLETED IN TWO AND ONE-HALF YEARS USING PUNCHED CARD MACHINES DESIGNED AND BUILT BY HOLLERITH.
EDMUND JAMES REF:32 WRITES THE CURRICULUM OF THE WHARTON SCHOOL OF FINANCIAL ECONOMICS.	1890	
EUGEN VON BOHM-BAWORK REF:20 DEVELOPS INVESTMENT DECISION ANALYSIS.	1890	
	1892	O. STEIGER REF: 7 BUILT A DIRECT MULTPLYING MACHINE WHICH USED TABLES.
	1892	LORD KELVIN REF: 4 BUILDS HARMONIC ANALYZERS AND SYNTHESIZERS TO ANALYZE FOURIER SERIES.
MINKOWSKI REF:49 WORKS ON LINEAR MODELS.	1896	
	1897	ALBERT A. MICHELSON REF:21 BUILDS A HARMONIC ANALYZER TO HANDLE FOURIER SERIES WITH 20 TERMS. THIS WAS LATER EXPANDED TO HANDLE 80 TERMS.
FREDERICH WINSLOR TAYLOR REF:39,48 DOES EFFICIENCY ANALYSIS ON PIG IRON HANDLING FOR THE BETHLEHEM STEEL COMPANY.	1898	
UNITED STATES REF:32 THE UNIVERSITY OF CHICAGO AND THE UNIVERSITY OF CALIFORNIA START BUSINESS SCHOOLS.	1898	
	1898	F. TAYLOR REF:39 BUILT A MECHANICAL PROGRAM CONTROLLED COMPUTER.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1900	ALLAN MARQUAND REF:21 BUILDS A MECHANICAL LOGIC SYLLOGISM SOLVER.
FARKAS REF:49 WORKS ON LINEAR MODELS.	1903	
ADMIRAL BRADLEY FISKE REF:17 ADMIRAL FISKE. UNITED STATES NAVY, PUBLISHED A PAPER WHICH ANTICIPATED THE ANALYTICAL METHODS OF FREDERICK LANCHESTER.	1906	
A.A. MARKOV REF:48 STUDIED SEQUENCES OF EXPERIMENTS.	1906	
	1906	H.P. BABBAGE REF: 7 COMPLETED PORTIONS OF HIS FATHER'S ANALYTICAL MACHINE, CORRECTING SOME ERRORS.
HARVARD REF:32 HARVARD SCHOOL OF BUSINESS STARTED.	1908	
A.K. ERLANG REF:39 FIRST ANALYZED TELEPHONE TRAFFIC CONGESTION FOR THE COPENHAGEN TELEPHONE COMPANY.	1909	
HARRINGTON EMERSON REF:33 COINED THE TERM ' SCIENTIFIC MANAGEMENT' DURING TESTIMONY ON THE UNITED STATES RAILROAD INEFFICIENCIES.	1910	
HENRY LAURENCE GANTT REF:38 HIS BOOK, //WORK, WAGES, PROFITS//, IS PUBLISHED.	1910	
HENRY LAURENCE GANTT REF:39,48 WORKED WITH PRODUCTION SCHEDULING.	1910	
FREDERICH WINSLOR TAYLOR REF:39,48 HE IS CONSIDERED THE FATHER OF SCIENTIFIC MANAGEMENT. PUBLISHED, //PRINCIPLES OF SCIENTIFIC MANAGEMENT//,NEW YORK: HARPER AND BROTHERS.	1910	
THOMAS EDISON REF:20 DEVELOPED OPTIMAL TACTICS FOR SUBMARINE EVASION HOWEVER HIS RESULTS WERE NOT USED BY THE MILITARY.	1914	
FREDRICK WILLIAM LANCHESTER REF:20,35 DOES EARLY 'OPERATIONS RESEARCH' TYPE OF WORK ON THE MATHEMATICAL ANALYSIS OF THE EQUATIONS OF CONFLICT. IT WAS NOT USED BY THE WWI MILITARY.	1914	
	1915	FORD INSTRUMENT COMPANY REF:13 DEVELOPED THE FIRST ANALOG COMPUTER.

OPERATIONS RESEARCH	DATE	COMPUTERS
FORD W. HARRIS REF: 6,20 DEVELOPS THE THEORY OF ECONOMIC LOT SIZE, A FORERUNNER TO ECONOMIC ORDER THEORY.	1915	
THOMAS EDISON REF:47 ELECTED CHAIRMAN OF BOARD OF 22 ENGINEERS TO ADVISE THE UNITED STATES NAVY ON NEW IDEAS.	1915 OC05	
THOMAS EDISON REF:47 IT WAS CALLED THE NAVAL CONSULTING BOARD OF THE UNITED STATES. PROJECTS INCLUDED PRODUCING A STANDARD SET OF SPECIFICATIONS FOR INDUSTRY IN WARTIME.	1915 OC05	
HENRY LAURENCE GANTT REF:39 SHOWED THE USE OF 'PRODUCTION PERFORMANCE CHARTS' IN //INDUSTRIAL LEADERSHIP//.	1916	
F.W. LANCHESTER REF:31 PUBLISHED 'AIRCRAFT IN WARFARE: THE DAWN OF THE FOURTH ARM'.	1916	
HENRY JOSEPH FAYOL REF:39,48 PUBLISHED IN FRANCE, //ADMISISTRATOR INDUSTRIELLE ET GENERALE//.	1916	
HENRY LAURENCE GANTT REF:38 HIS BOOK, //INDUSTRIAL LEADERSHIP//, IS PUBLISHED.	1916	
A.K. ERLANG REF:20 DEVELOPS THE WAITING LINE THEORY WHICH DEVELOPS INTO QUEUING	1917	
A.K. ERLANG REF:39 PUBLISHED 'SOLUTION OF SOME PROBLEMS IN THE THEORY OF PROBABILITIES OF SIGNIFICANCE IN AUTOMATIC TELEPHONE EXCHANGES'.	1917	
PERCY LUDGATE REF:34 PLANNED AND ORGANIZED PROVISION OF SUPPLIES FOR THE CAVALRY. THIS WAS AN EARLY INVENTORY CONTROL PROBLEM.	1917	
GALBIETH'S REF:39 FRANK B. AND LILLIAN E. GALGIETH PUBLISH //APPLIED MOTION STUDY//.	1917	
GANTT REF:38 AIDED IN PLANNED PRODUCTION OF THE AMERICAN WAR EFFORT. HIS BEST KNOWN ITEM WAS THE 'RIVETS DRIVEN' IN THE SHIPYARDS WHICH WAS GANTT'S MEASURE AND MOTIVATOR FOR SHIPYARD WORK.	1917	
A.K. ERLANG REF:39,48 WORKING FOR THE TELEPHONE COMPANY STUDIES FLUCTATION OF DEMAND.	1917	
M.T. COPELAND REF:33 //BUSINESS STATISTICS// BY COPELAND OF HARVARD IS PUBLISHED.	1917	

OPERATIONS RESEARCH	DATE	COMPUTERS
FRANK AND LILLIAN GALBRETH REF:39,48 DID TIME MOTION STUDIES FOR EFFICIENCY.	1917	
THOMAS EDISON REF:47 SUBMITTED HIS ANALYSIS OF SUBMARINE SINKINGS OF COASTAL SHIPPING AND HIS RECOMMENDATIONS. HE USED SIMULATION AND OPERATIONAL DATA TO DEVELOP THE ANALYSIS. NO OFFICAL ACTION WAS TAKEN.	1917 NO	
GANTT REF:38 HIS BOOK, //ORGANIZING FOR WORK//, IS PUBLISHED.	1919	
ERLANG REF:49 WORKS ON QUEUING.	1920	
	1920	LEONARDO TORRES YQUEVEDO REF:37 BUILT AN ELECTROMECHANICAL CALCULATOR WHICH WAS UNSUCCESS-FUL DUE TO NO NEED FOR ITS ABILITY TO COMPUTE.
LEWIS RICHARDSON REF: 2 DEVELOPED A MATHEMATICAL MODEL FOR PREDICTING THE WEATHER USING COMPLEX FORMULAS. UNFORTUNATELY THE LENGTHLY MATH MADE HIS 'PREDICTIONS' SIX DAYS LATE.	1922	
N. WIENER REF:48 THE FIRST CORRECT MATHEMATICAL CONSTRUCTION OF A MARKOV PROCESS IS DONE BY N. WEINER.	1923	
HAROLD HOTELLING REF:20 ADVANCES INVESTMENT DECISION ANALYSIS CLOSER TO CURRENT DECSION ANALYSIS.	1925	
COLUMBIA REF:32 THE COLUMBIA UNIVERSITY SCHOOL OF BUSINESS IS FOUNDED.	1926	
	1927	DR. VANNEVAR BUSH REF:21 BUILT AT M.I.T. AN EARLY ELECTRIC ANALOG COMPUTER FOR ANALYZING DIFFERENTIAL EQUATIONS.
THORNTON D. FRY REF:39 USED ERLANG'S APPROACH TO WAITING LINES FOR BELL TELEPHONE LABORATORIES.	1928	
JOHN VON NEUMANN REF:48 PROPOSED THE ESSENTIALS OF MODERN GAME THEORY.	1928	
	1929	DERRICK HENRY LEHMER REF:21 USES CARD STENSILS FOR A SYSTEM TO SEARCH FOR PRIME NUMBERS. THE METHOD WHEN IMPLEMENTED ON THE COMPUTER WAS KNOWN AS 'SIEVE SEARCH'.
HORACE C. LEVISION REF:21,39,48 DOES STUDY OF THE COD ON DELIVERY PROBLEM USING SOME VERY LARGE MATHEMATICAL MODELS BASED UPON EMPIRICAL DATA.	1930	

OPERATIONS RESEARCH	DATE	COMPUTERS
WALTER RAUTENSTRAUCH REF:20 FIRST USES A BREAKEVEN CHART FOR DECISIONS.	1930	
	1930 JA	BRITIAN REF:37 THE BRITISH THOMPSON HOUSTON STANDARD ELECTRIC TOTALISATOR DEVELOPED FOR HORSE RACE BETTING. THIS ACCUMULATOR COULD HANDLE 2000 BETS PER MINUTE.
	1931	DR. VANNEVAR BUSH REF: 4 BUILT A MECHANICAL DIFFERENTIAL ANALYZER. A VERSION OF THIS WAS USED IN WW II TO SOLVE BALLISTIC PROBLEMS.
WALTER SHEWHART REF: 6 INTRODUCED STATISTICAL QUALITY CONTROL IN INDUSTRY.	1931	
L.H.C. TIPPITT REF: 6 DEVELOPED WORK SAMPLING THEORY.	1934	
HAROLD HOTELLING REF:49 WORKS ON 'CANONICAL ANALYSIS'.	1935	
DR. HARRY HOPF REF:33 SUGGESTED THAT THE TIME WAS RIGHT TO TRANSFORM MANAGEMENT SCIENCE TO THE 'SCIENCE OF THE OPTIMUM'.	1935	
BRITISH AIR MINISTRIES REF:26 ESTABLISHED A COMMITTEE WITH SIR HENRY TIZARD AS CHAIRMAN AND P.M.S. BLACKETT, H.E. WIMPERIS, A.P. ROWE, AND A.V. HILL AS MEMBERS.	1935	
WASSILLY W. LEONTIEF REF:48 INTRODUCED INPUT/OUTPUT ANALYSIS IN THE ARTICLE, 'QUANTITATIVE INPUT-OUTPUT RELATIONSHIPS IN THE ECONOMIC SYSTEM OF THE UNITED STATES.'	1936 AG	
	1936 OC	IBM REF:13 FIRST LARGE IBM INSTALLATION AT U.S. SOCIAL SECURITY. IBM PUNCHED CARD EQUIPMENT ABLE TO PERFORM 120 MILLION POSTINGS A YEAR.
	1937	HOWARD H. AIKEN REF: 4,33 AIKEN OF HARVARD UNIVERSITY CONCEIVED THE AUTOMATIC SEQUENCE CONTROLLED CALCULATOR, MARK I.
BRITIAN REF:39,48 THE BRITISH HAVE SCIENTISTS WORKING ON THE RADAR PROBLEMS.	1937	
SIR ROBERT WATSON-WATT REF:21,39,48 LATER CLAIMS TO HAVE DONE OPERATIONS RESEARCH STUDIES AT THIS TIME.	1937	
JOHN VON NEUMANN REF:49 DEVELOPS SOPHISTICATED ECONOMIC MODELS.	1937	

OPERATIONS RESEARCH	DATE	COMPUTERS
	1938	LOUIS COUFFIGNAL REF:37 DIDA PH.D. DISSERTATION WHICH DESCRIBED A BINARY ELECTRO-MECHANICAL PROGRAM CONTROLLED CALCULATOR.
	1939	JOHN V. ATANASOFF REF:21,37 JOHN V. STANASOFF AND CLIFFORD E. BERRY DEVELOP A DIGITAL COMPUTER WITH LOGIC CIRCUITS TO HANDLE UP TO 30 SIMULTANEOUS LINEAR EQUATIONS.
L.K. KANTOROVICH REF:30,49 WORKED ON LINEAR PROGRAMMING FOR SOPHISTICATED ECONOMIC MODELS BUT HIS WORK WAS NOT REFERENCED OR USED UNTIL AFTER GEORGE DANTZIG'S WORK.	1939	
JOHN V. ATANASOFF REF:21 FIRST TO SEE THE VALUE OF GAUSSIAN ELIMINATION AS METHOD TO SOLVE SIMULTANEOUS LINEAR EQUATIOS INSTEAD OF DETERMINATES IN MECHANICAL SOLVERS. THIS METHOD WAS LATER IMPLEMENTED ON A COMPUTER.	1939	
KENDAL AND BABINGTON SMITH REF:48 PUBLISHED 100,000 RANDOM NUMBERS.	1939	
BRITIAN REF:41 BRITIAN'S ARMY OPERATIONAL RESEARCH GROUP FOUNDED. (AORG).	1939	
HEADQUARTERS FIGHTER COMMAND REF:21,39 THE RAF COLLECTS A GROUP OF SCIENTISTS TO STUDY THE PROBLEMS OF RADAR AND FIGHTER INTERFACE. THIS IS NOW RECOGNIZED AS THE FIRST 'OPERATIONS RESEARCH' GROUP OR OPERATIONAL RESEARCH AS IT WAS FIRST CALLED IN ENGLAND.	1939 SE	
MCCLOSKY AND TRAFETHEM REF:48 COIN THE TERM 'OPERATIONS RESEARCH'.	1940	
P.M.S. BLACKETT REF:21 HIS OPERATIONS RESEARCH GROUP IS STARTED TO STUDY ANTI-AIRCRAFT PROBLEMS.	1940	
	1940 JA	GEORGE STIBITZ REF:37 G. STIBITZ AND S.B. WILLIAMS OF BELL TELEPHONE LABORATORIES INVOLVED IN A COMPLEX NUMBER COMPUTER WHICH ADDS, SUTRACTS, MULTIPLIES, AND DIVIDES COMPLEX NUMBERS FOR FILTER NETWORK DESIGN PROBLEMS.
PROF. P.M.S. BLACKETT REF:39,48 THE BRITISH ANTI-AIRCRAFT COMMAND RESEARCH GROUP HEADED BY P.M.S. BLACKETT WAS FORMED. THE GROUP BECAME KNOWN AS 'BLACKETT'S CIRCUS'.	1940 SE	

OPERATIONS RESEARCH	DATE	COMPUTERS
DR. ELLIS A. JOHNSON REF:31,41 DR. JOHNSON OF THE NAVAL ORDANCE LABORATORY USES WAR-GAMING TO DEVELOP MODELS OF POSSIBLE MINING OPERATIONS WHICH WERE THEN TESTED WITH VARIOUS TACTICS AND WEAPONS. THESE STUDIES OF MINEWARFARE AND COUNTER MEASURE OPERATIONS RESULTED IN THE FIRST FORMAL UNITED STATES PUBLICATION IN MILITARY OPERATIONS RESEARCH.	1941	
HITCHCOCK REF:39 WORKS ON THE 'TRANSPORTATION TYPE PROBLEM'.	1941	
WASSELLY W. LEONTIEF REF:48 WROTE 'THE STRUCTURE OF THE AMERICAN ECONOMY, 1919-1939' WHEN INPUT/OUTPUT ANALYSIS WAS FIRST EXPLAINED.	1941	
	1941	KARL ZUSE REF:13 IN GERMANY, KARL ZUSE COMPLETED THE FIPST PROGRAM-CONTROLLED COMPUTER. IT WAS DESTROYED IN WW II.
F.L. HITCHCOCK REF:39 PRESENTED STUDY, 'THE DISTRIBUTION OF A PRODUCT FROM SEVERAL SOURCES TO NUMEROUS LOCALITIES'.	1941	
PROF. P.M.S. BLACKETT REF:47 WROTE A PAPER CALLED, 'SCIENTISTS AT THE OPERATIONAL LEVEL', WHICH EXPLAINED THE ROLE AND PURPOSE OF SCIENTIST IN MILITAR OPERATIONS.	1941	
OPERATIONAL RESEARCH GROUP REF:31 BLACKETT'S CIRCUS BECAME THE OPERATIONAL RESEARCH GROUP OF THE AIR DEFENSE RESEARCH AND DEVELOPMENT ESTABLISHMENT.	1941 MY	
PROF. P.M.S. BLACKETT REF:31 BECAME THE DIRECTOR OF NAVAL OPERATIONAL ANALYSIS AT THE BRITISH ADMIRALTY.	1941 DE	
WW II OPERATION REF:31 FIRST 1000 PLANE RAID OVER GERMANY IS A RESULT OF OPERATIONS RESEARCH INTO PLANE FORMATION LOSSES.	1942	
GENERAL SPAATZ REF:20 RECOMMENDED TO ALL COMMANDING GENERALS THE INCLUSION OF OPERATIONS ANALYSIS GROUPS ON THEIR STAFFS.	1942	
DR. WALTER MICHELS REF:31 THE NAVAL ORDNANCE LABORATORY OPERATIONAL RESEARCH GROUP WITH DR. WALTER MICHELS WAS ESTABLISHED TO STUDY MINE WARFARE. AT ONE TIME DURING THE WAR DR. JOHN VON NEUMANN WORKED WITH THIS GROUP.	1942 MR01	
UNITED STATES REF:21,48 THE UNITED STATES INITIATES OPERATIONS RESEARCH IN THE ARMY, OPERATIONAL EVALUATION IN THE NAVY, AND OPERATIONAL ANALYSIS IN THE ARMY AIR FORCE. THE FIRST PROBLEMS WERE RADAR AND CONVOYS.	1942 AP	

OPERATIONS RESEARCH	DATE	COMPUTERS
OPERATIONS RESEARCH GROUP REF:41 ANTI-SUBMARINE WARFARE OPERATIONS RESEARCH GROUP ESTABLISHED IN THE OFFICE OF THE CHIEF OF NAVAL OPERATIONS UNDER CIVILIA OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT WITH DR. PHILLIP MORSE AS DIRECTOR.	1942 MY	
DR. PHILLIP M. MORSE REF:31 HEADED A 7 MAN RESEARCH SECTION ANALYZING ANTISUBMARINE WARFARE.	1942 MY01	
	1942 AG	JOHN W. MAUCHLY REF:28 WROTE HIS MEMO ON THE ADVANTAGES OF AN ELECTRONIC HIGH SPEED COMPUTER FOR COMPUTING BALLISTIC CALCULATIONS FOR WW II ARTILLERY.
	1942 AG	JOHN W. MAUCHLY REF:29 MAUCHLY WROTE FIRST MEMO FOR ELECTRONIC COMPUTER.
UNITED STATES REF:10 UNITED STATES ARMY AIR CORP STARTS OPERATIONS RESEARCH SECTION FOR ANALYSIS OF BOMBING MISSION DATA.	1942 OC	
GENERAL H. ARNOLD REF:31 GENERAL ARNOLD'S LETTER TO RECOMMEND OPERATIONS ANALYSIS GROUPS TO ALL AIR FORCE COMMANDING GENERALS.	1942 OC24	
OPERATIONS ANALYSIS DIVISION REF:31 ESTABLISHED BY THE AIR STAFF.	1942 DE31	
	1943	ENGLAND REF:37 THE COLOSSI IS DEVELOPED IN ENGLAND FOR CODE BREAKING. THIS WAS A FORERUNNER FOR MOSAIC AND ACE.
OPERATIONS RESEARCH SECTION REF:10 FIRST RESULTS OF ORS IN 'THE FIRST 1100 BOMBERS'.	1943 MR	
	1943 AP	ECKERT AND MAUCHLY REF:28 J. PRESPER ECKERT AND JOHN W. MAUCHLY OF MOORE SCHOOL OF ELECTRICAL ENGINEERING, UNIVERSITY OF PENNSLYVANIA, PHIL., PA., SUBMITTED A PROPOSAL FOR AN ELECTRONIC DIFFERENCE ANALYZER. (BECOMES ENIAC).
	1943 JE	ENIAC REF:29 RESEARCH AND DEVELOPMENT BEGAN FOR THE FIRST ELECTRONIC COMPUTER.
DR. PHILLIP M. MORSE REF:31 HIS GROUP NOW HAS 40 MEN ATTACHED TO THE TENTH FLEET AS THE ANTISUBMARINE WARFARE OPERATIONS RESEARCH GROUP.	1943 JL	
	1943 JL01	UNITED STATES ARMY REF:28 CONTRACTED THE MOORE SCHOOL FOR RESEARCH AND DEVELOPMENT ON HIGH SPEED ELECTRONIC CALCULATING DEVICES.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1943 SE	GEORGE STIBITZ REF:37 BUILT A RELAY INTERPOLATOR WHICH DID HARMONIC ANALYSIS, ROOTS OF POLYNOMIALS, AND DIFFERENTIAL EQUATIONS. THIS WAS A A TAPE CONTROLLED MACHINE USED FOR FIRE CONTROL PROBLEMS.
COL W. BARTON REF:10 APPOINTED AS HEAD OF NEW OPERATIONS ANALYSIS SECTION FOR GENERAL ARNOLD.	1943 OC	
JOHN VON NEUMAN REF:48 JOHN VON NEUMANN AND MORGERSTERN WROTE //THEORY AND PRACTICE OF GAMES AND ECONOMIC BEHAVIOR//, WHICH WAS THE FIRST FORMAL WORK OF MODERN GAME THEORY.	1944	
OPERATIONS RESEARCH GROUP REF:31 PLANNED PATROL SYSTEM FOR THE ENTIRE SOUTH ATLANTIC WITH FOUR DAILY SORTIES OF B-24'S AND THE PBM'S FOUND FIVE GERMAN BLOCKADE RUNNERS.	1944 JA	
	1944 JE	E.L. VIBBARD REF:37 INVOLVED IN THE MODEL III SELF-CHECKING RELAY CALCULATOR.
OPERATIONS RESEARCH SECTION REF:10 COMPLETED ANALYSIS OF OPERATION 'COBRA'.	1944 JL	
G.J. STIGLER REF:39 DEVELOPS THE ORIGINAL 'DIET PROBLEM'.	1945	
	1945	JOHN VON NEUMANN REF:28 WROTE THE FIRST PROGRAM FOR EDVAC. NOTE: EDVAC WAS NOT YET BUILT. THE PROGRAM DID A SORT AND MERGE.
MILITARY ANALYSIS REF:33 ON V-J DAY THERE WERE ALMOST 500 ANALYSTS DOING OPERATIONS RESEARCH WORK FOR THE VARIOUS MILITARY COMMANDS.	1945	
LOS ALAMOS REF:39 MILITARY PROBLEMS WITH ATOMIC WEAPONS SOLVED BY USE OF MONTE CARLO METHODS.	1945	
OPERATIONS RESEARCH GROUP REF:31 OF SHIPS IN THE PACIFIC WHICH FOLLOWED THE OPERATIONS ANALYSIS RECOMMENDATIONS ABOUT MANEUVERS DURING KAMIKAZE ATTACKS WERE HIT 29 PERCENT OF THE TIME, WHILE THOSE WHO DID NOT FOLLOW THE DIRECTIONS WERE HIT 47 PERCENT OF THE TIME.	1945	
	1945	JOHN VON NEUMANN REF: 2 SUGGESTED THAT OPERATING INSTRUCTIONS AND DATA BE STORED IN THE MEMORY AND THE COMPUTER BE ABLE TO MODIFY THE INSTRUCTIONS UNDER PROGRAM CONTROL.
GENERAL H.H.ARNOLD REF:36 GENERAL ARNOLD, COMMANDING GENERAL OF THE ARMY AIR FORCES SUGGESTED A CONTRACT BETWEEN THE AAF AND DOUGLAS AIRCRAFT COMPANY. IT BECAME KNOWN AS PROJECT RAND.	1945	

OPERATIONS RESEARCH	DATE	COMPUTERS
	1945	JOHN W. MAUCHLY REF:29 PATENT #3,120,606 TO JOHN W. MAUCHLY AND J. PRESPER ECKERT FOR THE FIRST ELECTRONIC COMPUTER.
WW II END REF:31 USEG, ORO, OAD, RAND, OEG ALL ESTABLISHED.	1945	
OPERATIONS RESEARCH GROUP REF:31 RECOMMENDS THAT THE TACTICS ON ALL B-29 RAIDS OVER JAPAN BE CHANGED. GENERAL LEMAY SO ORDERED AND THE MISSION LOSSES WENT FROM 10-15 PERCENT TO 1-1.5 PERCENT.	1945 JA20	
OPERATIONS EVALUATION GROUP REF:17 EXTENDED INTO PEACETIME BY NAVY CONTRACT WITH MASSACHUSETTS INSTITUTE OF TECHNOLOGY.	1945 NO	
	1945 DE	ENIAC REF: 4,21 THE FIRST ELECTRONIC DIGITAL COMPUTER IS FINISHED.
RAND REF:36 THE FIRST STUDY WAS COMPLETED, 'PRELIMINARY DESIGN OF AN EXPERIMENTAL EARTH-CIRCLING SPACESHIP'.	1946	
	1946	BELL LABORATORIES REF:37 DEVELOP THE MODEL V CALCULATOR WHICH DOES MULTIPROCESSING, FLOATING POINT MATH IN A BATCH MODE.
JOHN VON NEUMANN REF: 2 ATTEMPTS WEATHER PREDICTION ON THE FIRST COMPUTERS.	1946	
OPERATIONS EVALUATION GROUP REF:17 PUBLISHED 'ANTISUBMARINE WARFARE IN WORLD WAR II.	1946	
	1946 FE	ENIAC REF:14 COMPLETED.
DOUGLASS AIRCRAFT COMPANY REF:41 PROJECT RAND STARTED WITH A GOVERNMENT CONTRACT.	1946 MR	
	1946 JL	ENIAC REF:29 ENIAC ACCEPTED BY ARMY.
WEAPONS SYSTEMS EVALUATION GP REF:53 THIS GROUP WAS ESTABLISHED AS A RESULT OF THE NATIONAL SECURITY ACT OF 1947. DONE IN THE FALL OF 1947.	1947	
T.C. KOOPMANS REF:39 PUBLISHED, 'OPTIMIUM UTILIZATION OF THE TRANSPORTATION SYSTEM'.	1947	
WEAPONS SYSTEMS EVALUATION GP REF:41 THIS GROUP WAS ESTABLISHED AS A RESULT OF THE NATIONAL SECURITY ACT OF 1947. DONE IN THE FALL OF 1947.	1947	

OPERATIONS RESEARCH	DATE	COMPUTERS
ENRICO FERMI REF:39 USED EXTENSIVELY MONTE CARLO TECHNIQUES IN HIS WORK.	1947	
DR. GEORGE B. DANTZIG REF:18,39,49 GEORGE DANTZIG AND MARSHALL WOOD DEVELOPED THE 'SIMPLEX' METHOD AND THE LINEAR PROGRAMMING PROBLEM MODEL SETUP TO BE USED AS A MANAGERIAL TOOL. DANTZIG AND LEADERMAN USED THIS TO SOLVE THE 'DIET PROBLEM' WITH 9 EQUATIONS, 9 SLACKS, AND 86 VARIABLES (BY HAND).	1947	
	1948	BELL LABORATORIES REF:13 DEVELOP THE TRANSISTOR.
CLAUDE SHANNON REF:31 WROTE IN THE BELL SYSTEM TECHNICAL JOURNAL, 'A MATHEMATICAL THEORY OF COMMUNICATION' WHICH DESCRIBED 'INFORMATION THEORY' FOR THE FIRST TIME.	1948	
ACM REF:24 ACM MET FOR THE FIRST PROCEEDINGS.	1948 AP	
OPERATIONAL RESEARCH SOCIETY REF:31 FORMED IN LONDON AS THE 'OPERATIONAL RESEARCH CLUB'. IT LATER BECAME THE 'SOCIETY' AND FOUNDED 'THE OPERATONAL RESEARCH QUARTERLY'.	1948 AP	
GENERAL RESEARCH OFFICE REF:41 OPERATIONS RESEARCH AT ARMY GENERAL STAFF STARTED BY CONTRACT WITH THE JOHN HOPKIN'S UNIVERSITY. IT WAS NAMED THE GENERAL RESEARCH OFFICE.	1948 JL	
	1948 OC	DEMON REF:45 DEMON PLACED IN OPERATION FOR NSA. FIRST PRACTICAL USE OF MAGNETIC DRUM FOR DATA STORAGE FOR ANALYTIC OPERATIONS AT ELECTRONIC SPEEDS.
RAND REF:36 THE RAND CORPORATION WAS FORMED AS AN INDEPENDANT AND NON-PROFIT ORGANIZATION.	1948 NO	
GENERAL RESEARCH OFFICE REF:41 RENAMED BY THE ARMY THE OPERATIONS RESEARCH OFFICE (ORO).	1948 DE	
MR. FORRESTAL REF:31 AUTHORIZED THE WEAPONS SYSTEM EVALUATION GROUP.	1948 DE11	
	1949	OTHER EARLY COMPUTERS REF:14 MARK III, BELL MODEL VI, AND BINAC WERE OPERATIONAL.
HENRY J. FAYOL REF:39 HIS WORKS FINALLY TRANSLATED AND PUBLISHED IN THE UNITED STATES.	1949	

OPERATIONS RESEARCH	DATE	COMPUTERS
RAND REF:22 FIRST USED THEIR FIRST COMPUTER TO DO MISSLE TRAJECTORY CALCULATIONS.	1949	
DR. HORACE C. LEVINSON REF:31 APPOINTED CHAIRMAN OF THE COMMITTEE ON OPERATIONS RESEARCH EXTABLISHED BY THE NATIONAL RESEARCH COUNCIL.	1949	
	1949	EDSAC REF:14,50 EDSAC AT CAMBRIDGE DOES FIRST SERIOUS COMPUTATION FOR THE MILITARY.
TRIPARTITE CONFERENCE REF:20 THE FIRST TRIPARTITE CONFERENCE ON ARMY OPERATIONAL RESEARCH HELD BETWEEN UNITED STATES, BRITAIN, AND CANADA FROM 21 TO 30 APRIL 1949.	1949 AP21	
	1949 MY	EDSAC REF: 5 EDSAC PERFORM THE FIRST FULLY AUTOMATIC CALCULATION.
	1949 AG	EDVAC REF:28 DELIVERED TO BALLISTIC RESEARCH LABORATORY AT ABERDEEN.
	1950	SEAC REF:14 ASSEMBLED AND WENT OPERATIONAL AT NATIONAL BUREAU OF STANDARDS (NBS).
	1950	RAND REF:22 RAND DECIDED TO BUILD JOHNNIAC AS AN IN HOUSE PROJECT IN LATE 1950.
UNITED STATES REF:48 IT IS RECOGNIZED THAT INDUSTRY HAS BEEN AIDED BY LINEAR PROGRAMMING, INVENTORY CONTROL, SIMULATION, AND PROBABILITY AND STATISTICS.	1950	
OPERATIONAL RESEARCH SOCIETY REF: 9 FOUNDED (BRITISH).	1950	
	1950	J.W. FORRESTER REF: 4 COMPLETES WHIRLWIND I WHICH WAS THE FIRST COMPUTER WITH FERRITE CORE MEMORY.
	1950 DE	ATLAS I REF:45 ATLAS I DELIVERED; OPERATIONAL IN ONE WEEK. FIRST PARALLEL ELECTRONIC COMPUTER IN U.S. WITH DRUM MEMORY. FORERUNNER OF COMMERCIAL E.R.A. 1101.
MORSE AND KIMBALL REF:33 WROTE THE FIRST OPERATIONS RESEARCH TEXT,"METHODS OF OPERATIONS RESEARCH".	1951	

OPERATIONS RESEARCH	DATE	COMPUTERS
OPERATIONS RESEARCH OFFICE REF:31 RECOMMENDED IN KOREA THAT THE B-29 BE USED FOR CLOSE SUPPORT BOMBING DUE TO NIGHT TIME REQUIREMENTS.	1951	
	1951	EDVAC REF:28 OPERATIONAL WITH THE NEEDED INPUT/OUTPUT DEVICES IN PLACE.
H.W.KUHN AND A.W. TUCKER REF:39 WROTE, 'NONLINEAR PROGRAMMING', AN ARTICLE USING LAGRANGIAN MULTIPLIERS.	1951	
JOHN VON NEUMANN REF:39 PUBLISHED 'MONTE CARLO METHODS', FIRST WORK ON THIS TOPIC.	1951	
	1951	MAURICE V. WILKES REF:13 MAURICE V. WILKES, DAVID J. WHEELER, AND STANLEY GILL AUTHORED THE FIRST BOOK ON PROGRAMMING, //THE PREPARATION OF PROGRAMS FOR AN ELECTRONIC DIGITAL COMPUTER//.
DR. PHILLIP M. MORSE REF:31 ELECTED FIRST PRESIDENT OF THE OPERATIONS RESEARCH SOCIETY OF AMERICA AT ITS FOUNDING.	1951 MY	
	1951 JE14	UNIVAC I REF:13 THE WORLD'S FIRST COMMERCIAL COMPUTER WAS DEDICATED AT THE U.S. BUREAU OF CENSUS.
CASE INSTITUTE OF TECHNOLOGY REF:31,48 IN CLEVELAND HELD THE FIRST UNITED STATES CONFERENCE ON THE APPLICATIONS OF OPERATIONS RESEARCH IN BUSINESS AND INDUSTRY.	1951 NO	
DR. GEORGE B. DANTZIG REF:39 SCOOP STUDIES (SCIENTIFIC COMPUTATION OF OPTIMUM PROGRAMS) BY USAF WITH DR. GEORGE B. DANTZIG AND MARSHALL WOOD. THIS PROJECT COVERED DEVELOPMENT OF COMPUTER IMPLEMENTATION OF LINEAR PROGRAMMING, ZERO-SUM GAMES AND THE LEONTIEF INPUT/OUTPUT MODELS.	1952	
ORSA REF: 9 OPERATIONS RESEARCH SOCIETY OF AMERICA IS FOUNDED (USA).	1952	
	1952	JOHN VON NEUMANN REF: 4 FINISHED WORK ON EDVAC WHICH WAS THE FIRST COMPUTER WITH INTERNAL BINARY REPRESENTATION, INTERNAL INSTRUCTION STROAGE, AND THE LARGEST MEMORY SO FAR.
	1952	ORDVAC REF:14 DELIVERED TO ABERDEEN PROVING GROUNDS.

OPERATIONS RESEARCH	DATE	COMPUTERS
SEAC REF:18,19 FIRST OPERATIONAL TEST OF A LINEAR PROGRAMMING PROBLEM. IT WAS DONE ON THE HIGH SPEED ELECTRONIC COMPUTER,SEAC, OWNED BY THE UNITED STATES NATIONAL BUREAU OF STANDARDS. THE PROBLEM WAS OF THE TRANSPORTATION TYPE OF LINEAR PROGRAMMING PROBLEM.	1952 JA	
	1952 MR10	ORDVAC REF:21 PASSES THE ACCEPTANCE TEST.
	1952 AP	ABNER REF:45 ABNER OPERATIONAL; DESIGNED AND BUILT BY NSA. SERIAL COMPUTER SIMILAR IN LOGIC TO SEAC AND EDVAC. MOST SOPHISTICATED COMPUTER OF ITS TIME. FIRST USE OF COMPUTATIONS SIMULTANEOUS WITH INPUT/OUTPUT.
	1952 SE01	ILLIAC REF:21 PASSES ITS ACCEPTANCE TEST.
	1952 OC	SHORTCODE REF:42 A DESCRIPTION OF SHORTCODE FOR UNIVAC WAS RELEASED. THIS WAS THE LANGUAGE SUGGESTED BY DR. JOHN MAUCHLY IN 1949.
ORSA REF:31 FIRST ISSUE OF 'JOURNAL OF THE OPERATIONS RESEARCH SOCIETY OF AMERICA' IS PUBLISHED.	1952 NO	
	1953	ATLAS II REF:45 ATLAS II DELIVERED TO NSA. FIRST U.S. USE OF CORE MEMORY INSTEAD OF ELECTROSTATIC STORES.
TIMS REF: 9 THE INSTITUTE OF MANAGEMENT SCIENCE IS FOUNDED (USA).	1953	
UNITED STATES REF:33 THE FIRST UNITED STATES OPERATIONS RESEARCH SOCIETY IS FOUNDED, THE OPERATIONS RESEARCH SOCIETY OF AMERICA (ORSA).	1953	
CONTINENTAL ARMY COMMAND REF:41 THE COMBAT OPERATIONS RESEARCH GROUP IS ESTABLISHED AT HEADQUARTERS, CONTINENTAL ARMY COMMAND, FT. MONROE.	1953	
	1953 JA	JOHN BACKUS REF:42 SUPERVISED THE WORK ON SPEEDCODING SYSTEM FOR IBM 701.
	1953 MR	IBM REF:15 FIRST IBM 701 ESTABLISHED IN NEW YORK.
D.P. GAVER REF:39 WRITES, 'THE INFLUENCE OF SERVICING TIMES IN QUEUING PROCESSES'.	1954	
A. COBHAM REF:39 WROTE, 'PRIORITY ASSIGNMENT IN WAITING-LINE PROBLEMS'.	1954 FE	

OPERATIONS RESEARCH	DATE	COMPUTERS
	1954 MR	JOHNNIAC REF:21 PASSES THE ACCEPTANCE TEST. THIS MACHINE WAS USED ON THE MANHATTAN PROJECT.
	1954 MY	OFFICE OF NAVAL RESEARCH REF:42 SPONSORED ONE OF THE FIRST MEETINGS ON AUTOMATIC PROGRAMMING 'SYMPOSIUM ON AUTOMATIC PROGRAMMING FOR DIGITAL COMPUTERS'.
RICHARD BELLMAN REF:39 DEVELOPED DYNAMIC PROGRAMMING AND PUBLISHED, 'SOME APPLICATIONS OF THE THEORY OF DYNAMIC PROGRAMMING'.	1954 AG	
J.L. HOLLEY REF:39 PUBLISHES, 'WAITING LINES SUBJECT TO PRIORITIES'.	1954 AG	
	1954 NO10	FORTRAN REF:42 THE DOCUMENT, 'PRELIMINARY REPORT,SPECIFICATIONS FOR THE IBM MATHEMATICS FORMULA TRANSLATING SYSTEM, FORTRAN', IS THE EARLIEST REFERENCE TO FORTRAN.
R.B. CATTELL REF: 4 R.B. CATTELL, CHARLES OSGOOD, AND L.L. MCQUILTY USED THE ILLIAC TO DO FACTOR ANALYSIS ON LARGE AMOUNTS OF PSYCHOLOGY DATA.	1955	
H.W. KUHN REF:39 PRODUCED AN ALGORITHM FOR THE ASSIGNMENT PROBLEM BASED ON EGERVARY'S THEOREM (1916).	1955	
NWB REF: 2 THE FIRST COMPUTER-GENERATED WEATHER FORECASTS WERE PRODUCED REGULARILY.	1955	
RAND REF:48 PUBLISHED 1,000,000 RANDOM NUMBERS.	1955	
E.I. DUPONT DE NEMOURS REF:47 INVESTIGATED THROUGHLY COMPUTER USAGE IN PLANNING, SCHEDULING, RESCHEDULING OF COMPANY ENGINEERING PROGRAMS.	1956	
	1956 JE	OMNICODE REF:42 SYMPOSIUM ON 'ADVANCED PROGRAMMING METHODS FOR DIGITAL COMPUTERS', WAS HELD. OMNICODE WAS DISCUSSED IN A PAPER.
	1956 OC	FORTRAN REF:42 FORTRAN I ISSUED.
AMERICAN UNIVERSITY REF:41 THE SPECIAL OPERATIONS RESEARCH OFFICE CONTRACTED FOR THE ARMY.	1957	
SYSTEM DEVELOPMENT CORPORATIONREF:36 WAS ORGANIZED AT THE REQUEST OF USAF OUT OF A RAND DIVISION. THE AIR DEFENSE SYSTEM WITH NEEDED CREW TRAINING WAS PART OF THEIR RESPONSIBILITY.	1957	

OPERATIONS RESEARCH	DATE	COMPUTERS
PERT REF:47 UNITED STATES NAVY SPECIAL PROJECTS OFFICE WITH BUREAU OF ORDINANCE AND BOOZ,ALLEN, AND HAMILITON DEVELOPED THE PROGRAM EVALUATION RESEARCH TASK (PERT) SYSTEM.	1957	
	1957 JE	LANGUAGE REF:42 SYMPOSIUM ON 'AUTOMATIC CODING' WAS HELD.
	1957 JE	NATIONAL SECURITY AGENCY REF:42 'LIGHTNING' HIGH-SPEED CIRCUITRY RESEARCHES UNDER WAY. MAY BE THE LARGEST U.S. GOVERNMENT COMPUTER RESEARCH SUPPORT.
	1957 JL	BOGART REF:45 BOGART DELIVERED TO NSA. BELIEVED TO BE THE FIRST PRACTICAL COMPUTER USING MAGNETIC (DIODE/CORE) LOGIC IN BASIC CIRCUITRY.
PERT REF:43 DEVELOPED FOR THE POLARIS PROJECT BY THE NAVY SPECIAL PROJECT OFFICE AND LOCKHEED AIRCRAFT CORPORATION WITH BOOZ, ALLEN, AND HAMILTON, A CONSULTING FIRM. THE PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT) IS BASED IN PART ON GANTT'S MILESTONE CHARTS.	1958	
	1958 MR	SOLO REF:45 SOLO DELIVERED TO NSA. FIRST COMPLETELY TRANSISTORIZED COMPUTER IN THE U.S.
	1958 JE	FORTRAN REF:42 FORTRAN II RELEASED
ROBERT SCHLAIFER REF:33 //PROBABILITY AND STATISTICS FOR BUSINESS DECISIONS// PUBLISHED BY SCHLAIFER OF HARVARD. IT CONTAINS THE FIRST PRACTICAL IMPLEMENTATION OF BAYESIAN STATISTICS.	1959	
D. HORST REF: 4 D. HORST, UNIVERSITY OF WASHINGTON, USED MULTIPLE REGRESSION FOR PREDICTION ON AN IBM 650. THE MODEL HAD 46 VARIABLES WITH 15000 CASES.	1960	
	1961	RAND REF:13 DEVELOPS SIMSCRIPT.
RESEARCH ANALYSIS CORPORATION REF:41 A NON-PROFIT ORGANIZATION BEGINS TO DO ARMY OPERATIONS RESEARCH.	1961 SE	
PERT/COST REF:48 DEVELOPMENT COMPLETED.	1962	
	1962	FORTRAN REF:42 FORTRAN IV RELEASED ON STRETCH.

OPERATIONS RESEARCH	DATE	COMPUTERS
	1962 FE	HARVEST REF:45 HARVEST DELIVERED TO NSA. THE 'TRACTOR' TAPE SYSTEM WAS THE FIRST COMPLETELY AUTOMATED TAPE LIBRARY.
FRANKLIN INSTITUTE REF:47 BEGAN TO MANAGE THE CENTER FOR NAVAL ANALYSIS.	1962 MR31	
	1962 DE	EDVAC REF:80 RETIRED.
ORSA REF: 1 HAS A LIST WHICH SHOWS THAT 188 FIRMS IN THE UNITED STATES USE OPERATIONS RESEARCH TECHNIQUES. IT IS CONSIDERED A PARTIAL LIST.	1963	
	1966 FE18	RAND REF:22 JOHNNIAC WAS DECOMMISSIONED BY RAND
AIDS REF: 9 AMERICAN INSTITUTE OF DECISION SCIENCES IS FOUNDED (USA).	1969	

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APPENDIX C

GOR COMPUTER SUPPORT USER'S GUIDE

Introduction

This is not an exhaustive list of computer support. There are many resources which could be included. The contents were chosen by an operations research graduate student whose bachelor's degree and Air Force specialty is computer science. The purpose is to concisely identify the most useful AFIT computer resources.

When only the title of a reference is given in the documentation, then it is on file in the computer room on top of the card file cabinets.

Contents

- System
  - INTERCOM
  - CREATE
- Operating System Resources
  - CCL
  - UPDATE
- General Languages
  - FORTRAN IV
  - SIMSCRIPT II.5
- Problem Solving Languages
  - OMNITAB II
  - SPSS
- Applications
  - IMSL

Operating System Resources

Cyber Control Language (CCL). This may be the most important resource. The CCL is very powerful and allows conditional tests, unconditional transfers, and control procedures. For the casual user of the INTERCOM system CCL is very valuable. With the use of a control procedure, it is possible to execute a long string of NOS/BE 1 commands with a single statement. During a thesis, the CCL could save a great deal of user time in those cases where the same sequence of commands or similar commands are made repeatedly.

Documentation:

NOS/BE 1 Reference Manual, pages 5-1 to 5-36.

UPDATE. The UPDATE program provides a method to maintain source program decks. UPDATE would be very useful in any large programming effort. It could be invaluable for a thesis program which has many areas of coding or declarations common to several routines or programs. The available options allow the user to manipulate source code with changes, inserts, deletions, copies, and purges. The manual is well written and has several good examples.

Documentation:

UPDATE Reference Manual

ASD Computer Center CDC NOS/BE User's Guide

General Languages

FORTRAN IV. The version of FORTRAN IV available at AFIT is very powerful and has many extensions on the CYBER 74 which can be very useful. For the GOR student, if you are planning to use the computer for your thesis or think you might, then try to take the Digital

System

INTERCOM. The INTERCOM system provides time sharing access to the Control Data CYBER 74 and CDC 6600 using the terminals located throughout AFIT. The user may use INTERCOM to either submit and control batch programs or to use the terminal in an interactive fashion. To use INTERCOM effectively, you need to understand a source language like FORTRAN or know how to use an application program. It is also important to be familiar with the NOS/BE 1 operations system and its commands.

Documentation:

INTERCOM Reference Manual

NOS/BE 1 Users Guide

NOS/BE Reference Manual

ASD Computer Center CDC NOS/BE User's Guide

CREATE. The CREATE system is the computer used at the School of Systems and Logistics. It can be used in a time sharing mode similar to INTERCOM. The library of available programs is very large and well documented. FORTRAN and BASIC are the two main source languages used on the CREATE system. Before you write any program to solve an operations research problem, especially for the thesis, check to see if it is already available on the CREATE system.

Documentation:

A Review of Computer Programs Relevant to the Air Force Institute of Technology, School of Systems and Logistics. SLTR 8-74. This document is available in multiple copies in the School of Systems and Logistics Library. It is excellent and contains detailed information on CREATE.

Computer Programming I, MA 5.65. This course will equip you to handle the large data manipulation problems often found in operations research problems. Otherwise, use the FORTRAN IV documentation carefully since there are often easy and hard ways to do the same thing.

DOCUMENTATION:

> _FORTRAN Extended Version 4 Reference Manual_, This is the key document with all the information and a copy is in the computer room. I suggest that if you plan to do any thesis programming that you purchase your own personal copy from the bookstore so you can mark it up with personal notes.
>
> _Other Books_. Just look up FORTRAN IV in the library for lots of programming and language information.

SIMSCRIPT II.5. This programming language is suited to general programming, system programming, and discrete-event simulation modeling. The implementation of SIMSCRIPT II.5 on the CYBER 74 is very efficient in execution. The language has the "structured if" and dynamic data management. This means that you can write very clear and easy to understand code. The data structures in this language allow the user many options not provided in FORTRAN. If you are interested in simulation as a possible thesis then take the SIMSCRIPT II.5 simulation course early.

Documentation:

> _SIMSCRIPT II.5 Reference Handbook_, C.A.C.I., 1976.
>
> _SIMSCRIPT II.5 User's Manual: Control Data Computer System_, C.A.C.I., 1976.
>
> _SIMSCRIPT II.5 Programming Language_, by Kiviat, Villanueva, and Markowitz.

Problem Solving Languages

OMNITAB II. While OMNITAB II is not a true computer language, it

appears that way to the user. This language is very useful for doing matrix maniputation with data that has been stored in a data structure best described as a column oriented worksheet. There are built in commands to do regression, statistical analysis, and many other specialized scientific functions. OMNITAB II can be very useful and fast if you have to do matrix operations to a set of data. It is much quicker than writing a FORTRAN program. See the second reference for details on how to use disk data files for input and output.

Documentation:

> OMNITAB II User's Reference Manual. This is the key document and it is well written. The School of Systems and Logistics' library has copies. It also can be purchased from the Superintendent of Documents, U.S. Government Printing Office. NBS Technical Note 552.
>
> OMNITAB II Programming Made Easy for Systems Analysts, SLTR 9-73. This document is also available in the School of Systems and Logistics' library. It is oriented around using the CREATE system. However the CYBER 74 OMNITAB II is the same once you start the program.

SPSS. If you have data which needs to be analyzed using statistical techniques, then SPSS is probably the best choice. This is a very extensive set of tools for the analyst in a single program package. SPSS was designed to be able to do multivariate analysis techniques.

Documentation:

> Statistical Package for the Social Sciences, by Nie, Hull, Jenkins, Steinbrenner, and Bent.
>
> An Introduction to: Applied Multivariate Data Analysis Course Notes, by McNichols. If your thesis uses survey data, then take this course, SM 6.85.

Application Programs

IMSL. This is a package of subroutines which do a variety of

mathematical applications. For the GOR student, when you are forced to write your own FORTRAN program because you could not find it already written, then the IMSL must be the next place to look. IMSL may provide subroutines which can do much of the work in an applications program. The most attractive thing about IMSL is that it is constantly being improved and maintained. The IMSL routines are efficient, well documented, and easy to use.

Documentation:

IMSL Reference Manual, Volume I and Volume II.

APPENDIX D

LIST OF AVAILABLE OPERATIONS RESEARCH ALGORITHMS WITH BIBLIOGRAPHY REFERENCES

Introduction

The format used is like an index and is easy to use. The numbers on the right hand side are the reference number and page number if available.

The bibliography is located at the end of this appendix. Every item is a FORTRAN source listing unless noted otherwise.

Another excellent source of algorithms is the book, Operations Research Handbook: Standard Algorithms and Methods, by Horst A. Eiselt and Helmut Von Frajer. This book contains 107 different algorithms in a clear step-by-step presentation.

Assignment	
Hungarian algorithm-	(5:121)
Simplex- max 10 by 10	(13:244)
Classical Calculus	
SOLN-CREATE-find roots of 1 variable function	(6)
MAXOPT-CREATE-find max of up to 10 variable function	(8)
ZEROS-CREATE-find roots/extrema of bounded function	(6)
ZXMIN-IMSL-find min of n-variable function	(9)
ZBRENT-IMSL-find roots of bounded function	(9)
Decision Analysis	
Bayes decision procedure with and without data	(5:395)
Bayesian analysis, max 4 states, 2 actions, 3 observ.	(13:432)
Decision making under uncertainty max 10 states, 10 alt	(13:546)
Dynamic Programming	
Investment problem	(13:25)
Stagecoach problem	(13:36)
Inventory problem	(13:48)
Equipment replacement problem	(13:59)
Economic Life	
Determination of economic life for one item	(13:284)
Flowcharter	
A CDC program makes flowcharts of FORTRAN or COBOL	(16)
Game Theory	
Brown's algorithm for a finite matrix game	(5:428)
Integer Programming	
INTLP-CREATE-max 14 variables, 16 constraints	(8)
Zero-one algorithm	(11.425)
Branch and bound-Land and Doig	(11:474)
Zero-one with implicit enumeration	(12:178)
Cutting Planes, max 30 variables, 30 constraints	(12:227)
Branch and bound	(3:732)
Implicit enumeration	(5:153)
Gomroy's cutting plane	(5:173)
Branch and bound-Eastman's algorithm-traveling sales	(5:207)
Branch and bound-Kolesar's algorithm-backpack load	(5:229)

Inventory	
EOQ model	(13:327) (13:329) (13:341)
Perishables and variable demand	(13:454)
Variable demand	(13:447)
Lead time with opportunity costs, max 8 lead time prob.	(13:467)
Probabilistic model	(5:542) (5:556)
Investment Proposal Analysis	
By equivalent present value, max 5 proposals, 10 years	(13:272)
Knapsack Problem	
Single dimension	(11:470)
Leontief Input/Output Analysis	
Parts requirement , m,n less than 11	(13:161)
Linear Programming	
LINPROG-CREATE- max 50 variables, 30 constraints	(8)
LINPRO-CREATE- max 30 variables, 18 constraints	(8)
ZX1LP/ZX2LP/ZX3LP-CYBER- revised simplex	(9)
UHELP-CREATE- max 50 variables, 25 constraints	(4)
Simplex	(11:413)
Separable programming problem	(11:451)
Simplex, max 30 variables, 30 constraints	(12:212)
LP program	(3:724)
LP program	(1:353)
Simplex	(5:101)
Simplex, max 20 variables, 10 constraints	(13:206)
MACSYMA- this is a program which can do symbolic math	(2) (15)
Markov Chains	
Analysis	(5:585)
Matrix Reduction	
Gauss-Jordon method	(5:606)
Gauss reduction procedure	(13:144)
PERT/CPM	
PERT	(5:448)

CPM	(13:401)
PERT	(13:412)
PROSE- a calculus based optimizing language	(14)
Queuing	
Single queue, single server	(13:494)
M queue, S servers	(5:482)
Arbitrary distribution of the service time	(5:493)
Simulation of single queue, single server	(5:514)
Regression Analysis	
Least squares polynomial regression	(5:341)
Simple linear regression	(5:375)
Least squares linear regression	(13:84)
Forecast by moving averages	(13:92)
Forecast by exponential smoothing	(13:105)
Forecast by least squares with seasonal variations/trend	(13:115)
Sequencing	
N jobs through 2 machines	(5:275)
N jobs through 3 machines	(5:283)
Transportation	
TRANSPRO-CREATE- max 20 by 20	(8)

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APPENDIX E

HANDOUT ON THE USE OF "LPKODE" FOR LINEAR PROGRAMMING

Introduction

This handout has the following information:

1) Data deck setup

   a. Without constraint and variable labels

   b. With constraint and variable labels

2) Running from Batch

3) Running from INTERCOM

The LPKODE program solves linear programming problems formulated in the following fashion:

$$\text{MIN or MAX of } Z = \sum_{L=1}^{N} C_i \; X_i$$

Subject to:

$$\begin{array}{lll} \displaystyle\sum_{i=1}^{N} a_{1i} \; X_i & \langle\text{relation}\rangle & b_1 \\ \vdots & \vdots & \vdots \\ \displaystyle\sum_{L=1}^{N} a_{ki} \; X_i & \langle\text{relation}\rangle & b_k \end{array}$$

Note: The relation may be ($\leq$, $\geq$, or =)

Please observe this allows much easier problem formulation and interpretation of the results. You do not have to determine the slacks or artificals for LPKODE. For more guidance on formulation see Operations Research, Second Edition, Hillier and Lieberman.

Example: The modified Wyndor Glass Company as formulated on page 65 of Hillier and Lieberman.

$$
\begin{array}{llrcrcl}
\text{MIN of } Z = & 3X_1 & + & 5X_2 & & \\
\text{S.T.} & X_1 & & & \leq & 4 \\
 & & & 2X_2 & = & 12 \\
 & 3X_1 & + & 2X_2 & \geq & 18 \\
 & X_1, & & X_2 \geq 0 & &
\end{array}
$$

This handout explains a subset of the options for LPKODE. For more information, refer to a handout filed with Major Dunne. However, be forewarned that much of that write-up is dated or wrong. LPKODE <u>will not</u> do integer or mixed integer problems (it never has in its 10+ years at AFIT). It can do transportation problems but the results are inconsistent. I do not personally recommend the use of the transportation section of LPKODE.

1) <u>Data Deck Setup</u>

NOTE: LPKODE is <u>very strict</u> on input format. Almost all program crashes are due to wrong formating of the data. You have two choices on how to make up the data set.

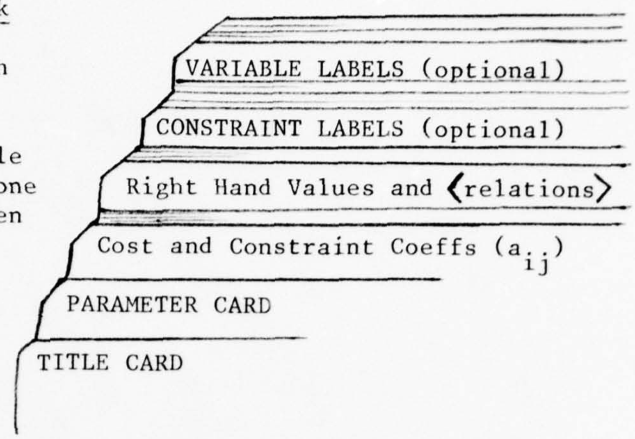
a. Punch cards to get a data deck (Useful for <u>large</u> problems).

b. Use INTERCOM and EDITOR/CREATE to make up a data file (Catalog or store it to conserve your effort).

Overview of a data set deck

This is the group of cards which make up one set of data.

LPKODE allows you to run multiple data sets if you just put them one after another. LPKODE quits when out of data.



CARD TYPE: TITLE CARD Format: (6A10)

Use the first 60 columns of the card for a title of up to 60 characters long. (Do not put two :'s together).

EXAMPLE:

THE MODIFIED WYNDOR GLASS COMPANY--H&L ANS: (2,6) Z=36
↑Col 1 ↑Col 60

CARD TYPE: PARAMETER CARD Format: (3I2,A3,2I2)

1-2	3-4	5-6	7-8-9	10	11
m	n	OPT	MAX or MIN	A	B

m: number of rows in the constraint matrix

n: number of columns in the constraint matrix excluding any slack and/or artificials.

OPT: Print Option (choice of output on TAPE 2)

-2 First matrix, last matrix, and each basis

-1 All matrices after each iteration

00 Original and final matrix only

1 Each basis

A: MUST BE BLANK

B: Flag for labels

0 No labels in this data set

1 Yes labels in this data set

EXAMPLE:

```
 3 201MIN 1
↑         ↑
Col 1     Col 11
```

CARD TYPE: Cost and Constraint Coef's   Format: (7(2I2,F6.2))

1-2	3-4	5- --- -10	11-12	13-14	. . .	65- --- -70
i	j	a_{ij}	i	j		a_{ij}

Set of Values

Enter seven or less sets of values per card.

You may order the sets of values in any order.

NOTE: i row number (==0 for cost coeff C_i)

j column number (IF ==0 then this set of values (i,j,a_{ij}) is skipped).

Enter -1-1 for the i and j values after the last cost or constraint coefficient has been entered.

EXAMPLE:

```
0001      30002     5
0101      10202     2
0301      3         ↑
0302      2-1-1     |
↑                   |
Col 1               Col 20
```

CARD TYPE: Right Hand Values and Relations   Format: (I2,A2,F6.0)

1-2	3-4	5- --- -10	11-12	13-14	. . .	65- --- -70
j	$type_j$	b_j	j	$type_j$		b_j

Set of Values

Enter seven or less sets of values per card.

If j==0 then that set of values ($j,type_j,b_j$) is skipped.

Enter -1 for j after your last set of values.

The sets of values may be in any order but the j = -1 must be the last number in the sets of data.

NOTE: j row number of the b_j value

$type_j$ LT -- less than or equal b_j or $\leq$

GT -- greater than or equal b_j or $\geq$

ET -- equal to b_j or =

b_j right hand value (any real or integer which will fit in the six spaces).

EXAMPLE:

```
01LT      4
02ET    1203GT    18
-1
↑                 ↑
Col 1             Col 20
```

CARD TYPE: <u>VARIABLE LABELS</u> Format: (8A8)

If you set B = 1 on the PARAMETER card then you <u>MUST include labels</u>.

If you set B = 0 on the PARAMETER card then you <u>MUST NOT include label cards</u>.

1- --- -8	9- --- 16	17- --- -24	...	49- --- -56
label	label	label		label

label Any string of up to 8 characters or numbers. You may use any character except : .

The constraint labels come first as a set. Then the variable labels are on the next set of cards starting in column 1.

Note: These are two separate sets, and each set must start on column 1 and continue with continuous groups of 8 labels per card until the last card of each set which may have 8 or less labels.

```
EXAMPLE:

PLANT 1 PLANT 2 PLANT 3
↑CAP #1   CAP #2      ↑
|                     |
Col 1                 Col 24
```

2) Running from Batch

Your deck from beginning to end is as follows:

```
Col 1

XXX,CM60000.          T720155,YOURNAME,YOURBOXNUMBER.

ATTACH,LPKODE.

LPKODE.

ROUTE,TAPE2,DC=PR,TID=BB,FID=XXX,ST=CSB.
```

7/8/9 (Multipunch card)

Set of data cards as described before (one or more problems).

6/7/8/9 (Orange end of job card)

```
    EXAMPLE:

    RMS,CM60000.      T720155,SCHUMACHER,4285.
    ATTACH,LPKODE.
    LPKODE.
    ROUTE,TAPE2,DC=PR,TID=BB,FID=RMS,ST=CSB. (optional card for full output)
  7/8/9
    THE MODIFIED WYNDOR GLASS COMPANY--H&L ANS: (2,6) Z=36
     3 201MIN 1
    0001      30002      5
    0101      10202      2
    0301      3
    0302      2-1-1
    01LT       4
    02ET      1203GT    18
    -1
    PLANT 1 PLANT 2 PLANT 3
     CAP #1   CAP #2   CAP #3
6/7/8/9
```

3) Running from INTERCOM

LOGIN with the Systems Management ID (T720155) and the assigned

password.

Next obtain the LPKODE program with this command.

ATTACH,LPKODE.

Now you must either attach your own data set or make one up using the EDITOR/CREATE. Just remember that the data cards MUST NOT have sequence numbers when you save the data set into a temporary filename DATA.

If the data is in a file called DATA and the file is rewound, your next command is:

LPKODE,DATA.

After the run if you want the full long printout, it is in a file called TAPE2, and you can get a copy of it with this command:

ROUTE,TAPE2,DC=PR,TID=BB,FID=XXX,ST=CSB.

If you do not want to see all of the terminal's output while the problem is running, then you can execute the program and put the output into a temporary file. Use:

LPKODE,DATA,TEMP.

Now you can either ROUTE or PAGE the file TEMP.

APPENDIX F

CHECKLIST FOR EVALUATING COMPUTER SUPPORT FOR GRADUATE OPERATIONS RESEARCH EDUCATION

Item or Section	Not Rated	Positive Factor	Negative Factor	Data Source
I. Potential Support				
A. Software				
1. Operating Systems				
2. High Level Languages				
3. Applications Programs				
4. Documentation				
B. Hardware				
1. Computer				
a. Speed				
b. Size				
c. Accuracy				
d. Size of the System				
2. Peripheral Devices				
a. Classical Input/Output				
b. Graphical Devices				
c. Remote Terminals				
3. Mass Storage				
a. Size				
b. Speed				
c. Accuracy				
d. Ease of Use				
4. Physical Facility				
a. Location				
b. Size				
c. Work and Study Space				
C. Personnel				
1. Computer Experts				
2. Operations Research Applications Experts				
3. Interface Experts				

Item or Section	Not Rated	Positive Factor	Negative Factor	Data Source
D. Plans				
1. Computer				
a. Software				
b. Hardware				
c. Personnel				
d. Plans				
2. Curriculum and Computer				
a. Operating System				
b. Application Programs				
c. High Level Languages				
d. Documentation				
e. Needed Abilities or Programs				
f. Relationships Between Academic Courses				
II. Actual Support				
A. Faculty				
1. Training				
2. Use of Computer Support				
3. Evaluation				
B. Students				
1. Training				
2. Use of Computer Support				
3. Evaluation				

APPENDIX G

SAMPLE RUN OF THE LINEAR PROGRAMMING PREPROCESSOR

The problem which was formulated using the preprocessor is from Hillier and Lieberman's textbook, Operations Research Second Edition, on page 65. This problem was also used as an example in Appendix E.

All of the user inputs have been underlined for clarity.

The last page of this appendix is a listing of the file made up by this program for LPKODE. It may be compared with the suggested data deck in Appendix E.

```
          WELCOME TO GORLPP
  GRADUATE OPERATIONS RESEARCH LINEAR PROGRAMMING
           PREPROCESSOR.
PLEASE USE THE FOLLOWING METHOD TO ANSWER QUESTIONS
    IF THE QUESTION IS A YES/NO TYPE QUESTION (ANS>).
USE...      Y  FOR YES
            N FOR NO
            HELP FOR MORE INFORMATION
            QUIT TO LEAVE GORLPPS IMMEDIATELY
FOR QUESTIONS WHICH WANT A SINGLE INTEGER NUMBER (INT>)
 USE...    AN INTEGER FOR THE DESIRED INPUT ANSWER
           -123456789  FOR HELP
           -9876543219  TO QUIT IMMEDIATELY
ARE YOU AN EXPERT IN THIS PROGRAM? ANS>Y

ARE YOU GOING TO MAKE A NEW DATA SET? ANS>Y

IS THIS AN INTEGER/MIXED INTEGER PROBLEM? ANS>N

TOTAL # OF VARIABLES (EXCLUDE ARTIF. AND SLACK)? INT>2

TOTAL NUMBER OF CONSTRAINTS? INT>3

TITLE OF THIS PROBLEM IN 40 SPACES OR LESS
>MODIFIED WYNDOR GLASS COMPANY H&L PG 65

DO YOU WANT TO LABEL VARIABLES AND EQUATIONS? ANS>Y
```

```
READY TO INPUT LABELS? ANS>Y

OBJECTIVE NAME: COST

INPUT NEW VARIABLE NAMES
 X1: CAP $1

 X2: CAP $2

 INPUT NEW CONSTRAINT NAMES
 CONST 1: PLANT 1

 CONST 2: PLANT 2

 CONST 3: PLANT 3

 IS THIS A MAX OR A MIN PROBLEM(ENTER MAX OR MIN)?>MIN

 IF THE TERMINAL IS EXTRA QUIET FOR A LONG TIME YOU MAY
 NOT HAVE ENTERED ENOUGH DATA SO RECOUNT THE NUMBER OF
 DATA POINTS.
 DO YOU KNOW HOW TO ENTER LIST/DIRECTED DATA? ANS>Y
```

```
 INPUT THE COEF OF THE OBJECTIVE FUNCTION
 3,5

MIN THE COST      OF
 3.00      CAP $1   5.00      CAP $2
 IS THIS EQUATION OK? ANS>Y

INPUT COEFFICENTS FOR CONSTRAINT $  1
1,0

 INPUT GE FOR >=,LE FOR <=,OR EQ FOR =  ?LE

 INPUT RIGHT HAND VALUE B(1)4

PLANT 1
 1.00      CAP $1   0.        CAP $2
        LE      4.00
 IS THIS EQUATION OK? ANS>Y

INPUT COEFFICENTS FOR CONSTRAINT $  2
0,2

 INPUT GE FOR >=,LE FOR <=,OR EQ FOR =  ?EQ

 INPUT RIGHT HAND VALUE B(2)12

PLANT 2
 0.        CAP $1   2.00      CAP $2
        EQ      12.0
 IS THIS EQUATION OK? ANS>Y
```

```
INPUT COEFFICENTS FOR CONSTRAINT $  3
3,2

 INPUT GE FOR >=,LE FOR <=,OR EQ FOR =  ?GE

 INPUT RIGHT HAND VALUE B(3)18

PLANT 3
 3.00      CAP $1    2.00      CAP $2
         GE       18.0
 IS THIS EQUATION OK? ANS>Y
```

```
ECHO OF THE CURRENT PROBLEM BEING SET UP FOR SOLUTION

MIN THE COST     OF
 3.00      CAP $1   5.00      CAP $2
 SUBJECT TO THESE CONSTRAINTS


PLANT 1
 1.00      CAP $1   0.        CAP $2
        LE       4.00
PLANT 2
 0.        CAP $1   2.00      CAP $2
        EQ       12.0
PLANT 3
 3.00      CAP $1   2.00      CAP $2
        GE       18.0
 CHOOSE THE OPTION FOR CHANGES.  YOU WILL BE ALLOWED TO
 MAKE MORE THAN ONE CHANGE, BUT THEY ARE MADE ONE AT A
 TIME.
 OPTION         ACTION          OPTION       ACTION
 -123  I QUIT NOW               11  ADD A VARIABLE
 0  NO MORE CHANGES             12  DELETE A VARIABLE
 1  REECHO THE PROBLEM          13  ADD A CONSTRAINT
 2  REPEAT OPTION LIST          14  DELETE A CONSTRAINT
 3  NEW VARIABLE NAME           15  CONVERT TO THE DUAL N/A
 4  NEW CONSTRAINT NAME         16  CHANGE DECISION
 5  NEW OBJECTIVE NAME              VARIABLES TO OR FROM
 6  CHANGE MIN TO MAX               INTEGER. N/A.
              OR                17  DUMP OF WORK
          MAX TO MIN            18  DUMP OF LABELS
 7  CHANGE OBJECTIVE FUNCTION   19  STATUS AREA DUMP
    COEFFICIENTS                20  RESCALE A VARIABLE
 8  CHANGE THE(GE,LE,EQ)        21  RESCALE A CONSTRAINT
 9  CHANGE RIGHT HAND VALUES
 10 CHANGE A CONSTRAINT
    COEFFICIENT
```

```
OPTION >0

 CHOOSE THE NEXT PROGRAM OPTION.
   OPTION      ACTION
   1          SETUP FOR LPKODE SOLUTION
   2          SET UP FOR MIX INTEGER PROBLEM
   3         SETUP FOR EASY SIMPLEX
   4         EXIT GORLPP NOW WITH TAPE1
   5         EXIT AND EXECUTE LINEAR PROBLEMS SET UP SO FAR
 OPTION>1

 PRINT OPTIONS FOR LPKODE SETUP
  -2 FIRST MATRIX, LAST MATRIX AND EACH BASIS
  -1  ALL MATRICES AFTER EACH ITERATION
  00 ORIGINAL AND FINAL MATRIX ONLY
    1  EACH BASIS
 OPTION>-2

 OPTIONS AFTER LPKODE SETUP FOR THE TAPE2 FILE
      1     EXIT NOW WITH THE TAPE2 FILE
 2  SET UP FOR A NOTHER TYPE PROBLEM
 3  MODIFY THIS ONE FOR A NOTHER DATA SET
 OPTION AFTER LPKODE SETUP?  OPTION>1

 THIS IS A GRACEFUL EXIT YOU HAVE A TAPE1 AND A TAPE2
     STOP   USER STOP AFTER LPKODE SETUP
```

```
MODIFIED WYNDOR GLASS COMPANY H&L PG 65  BY GORLPP 11/28/78
 3 2-2MIN 1
 0 13.0000 0 25.0000 1 11.0000 2 22.0000 3 13.0000 3 22.0000
-1-1
 1LT4.0000 2ET12.000 3GT18.000
-1
PLANT 1 PLANT 2 PLANT 3
CAP $1  CAP $2
```

VITA

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
AFIT/GOR/SM/78D-13

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
SURVEY AND EXTENSION OF COMPUTER RESOURCES TO SUPPORT GRADUATE OPERATIONS RESEARCH EDUCATION

5. TYPE OF REPORT & PERIOD COVERED
MS Thesis

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Robert M. Schumacher
Capt, USAF

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Air Force Institute of Technology (AFIT-EN)
Wright-Patterson AFB, Ohio 45433

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Department of Systems Management
AFIT/EN

12. REPORT DATE
December 1978

13. NUMBER OF PAGES
157

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Approved for public release; IAW AFR 190-17

JOSEPH P. HIPPS, Major, USAF
Director of Information 19 Jan 79

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Computer History
Operations Research History
Computer Support
Operations Research Education
Problem Formulation
Algorithm Selection
FORTRAN

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The historical relationship between operations research and the computer was analyzed based upon a search of the literature. The historical data was compiled into a timeline and a 50 item bibliography. A model of computer support for graduate operations research education was developed. A checklist based upon this model was used to evaluate portions of the Air Force Institute of Technology's Graduate Operations Research program. Based upon a literature search, a proposal for an automated method for algorithm selection was developed.